# SEISMIC SAFETY ELEMENT

CITY OF SAN LUIS OBISPO
JULY 1975

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# PART 1: POLICY STATEMENT

# I. INTRODUCTION

## A. LEGISLATIVE AUTHORITY

The California State Legislature, through the requirement of the Seismic Safety Element, has placed specific responsibility on local government for identification and evaluation of earthquake hazards and formation of programs and regulations to reduce risk. Specific authority is derived from Government Code Section 65302(f) which requires a Seismic Safety Element of all city and county general plans, as follows:

"A Seismic Safety Element consisting of an identification and appraisal of seismic hazards such as susceptibility to surface ruptures from faulting, to ground shaking, to ground failures, or to the effects of seismically induced waves such as tsunamis and seiches.

"The Seismic Safety Element shall also include an appraisal of mudslides, landslides, and slope stability as necessary geologic hazards that must be considered simultaneously with other hazards such as possible surface ruptures from faulting, ground shaking, ground failure, and seismically induced waves."

The effect of this section is to require cities and counties to take seismic hazards into account in their planning programs. The principal catalyst for this requirement was the February 9, 1971 San Fernando earthquake in which 65 people were killed and property damage exceeded the billion dollar mark. Conclusions from the 1973 Urban Geology Master Plan for California also provide cause for considering geologic hazards in the planning process. Summary conclusions from this study estimate that dollar losses due to geologic hazards in California between 1970 and 2000 will amount to more than $55 billion (Figure 1).

## B. PURPOSE AND APPROACH

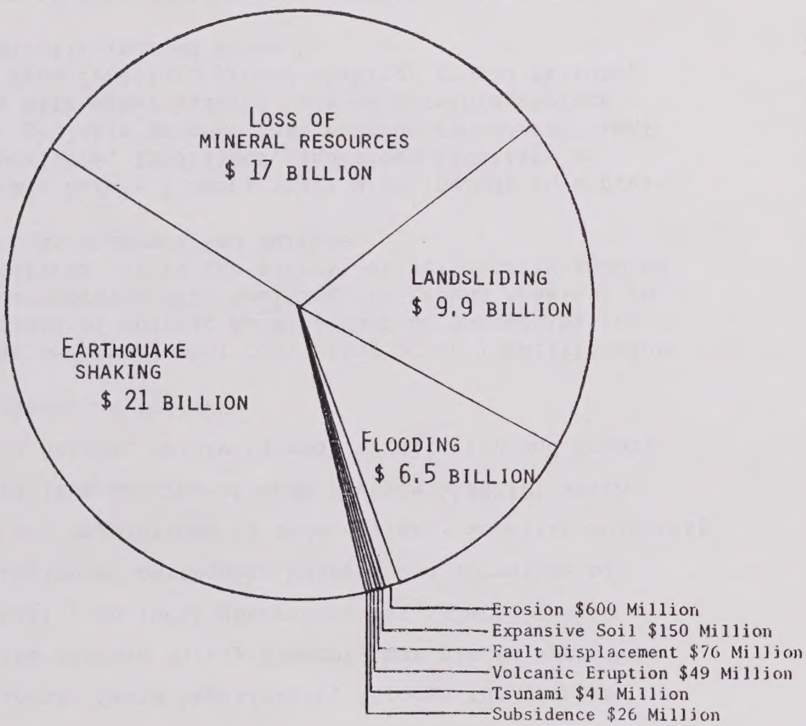
The basic objectives of the Seismic Safety Element are to identify and evaluate seismic hazards confronting cities and counties and to recommend policies that would reduce the adverse impact of those hazards if they are realized.

Specifically, the Element evaluates both primary and secondary seismic hazards, including ground shaking, liquefaction and settlement potential, and landsliding. The intent of the recommended policies is to provide an opportunity to reduce the loss of life, property damage, and social and economic dislocations in the event of a major earthquake.

The Seismic Safety Element is intended to serve as an official guide to the City Council and the Mayor, the Planning Commission and other governmental bodies, citizens, and private organizations concerned with seismic hazards in the City of San Luis Obispo. The recommendations contained in this document are intended to establish uniformity of policy and direction within the City government to minimize risk from earthquakes. The Element includes goals, policies, safety criteria, and maps as a basis for decision-making in public

Figure 1.

GEOLOGIC HAZARDS IN CALIFORNIA
TO THE YEAR 2000:
A $55 BILLION PROBLEM




Source: Urban Geology, Master Plan for California, Bulletin 198, 1973.

and private development matters. Such information is to be used in conjunction with other established City policies contained in the General Plan, and should play a major role in determining future land use.

The Seismic Safety Element has been prepared as a single document for the City of San Luis Obispo in two component sections. The first, the Policy Statement, is concerned with the implications of the technical findings for the City, while the second, the Technical Analysis, addresses the nature and extent of seismic hazards. It should be noted that the science of seismology is relatively young and that much remains to be learned. The basic philosophy under which this document was prepared is that we should account for seismic hazards in the planning process based on what we know today, rather than waiting until we know all that we would like to know.

# II. EXISTING CONDITIONS

A. TYPES OF HAZARDS

There are several types of seismic hazards which can be grouped in a cause-and-effect classification that is the basis for the order of their consideration in this report. Earthquakes originate as shock waves generated by movement along an active fault. The primary seismic hazards are ground shaking and the potential for ground rupture along the surface trace of the fault. Secondary seismic hazards result from the interaction of ground shaking with existing soil and bedrock conditions, and include liquefaction, settlement, landslides, tsunamis, or "tidal waves", and seiches (oscillating waves in lakes and reservoirs).

The potentially-damaging natural events listed above may interact with man-made structures. If a structure is unable to accommodate the natural event, failure will occur. The potential for such failure is termed a structural hazard, which may be considered in terms of primary and secondary hazards also. The failure of the structure itself is considered a primary hazard while the movement of inadequately restrained objects within, on, or adjacent to a structure are considered secondary structural hazards. Consideration of secondary hazards is particularly important in assessing the seismic vulnerability of facilities that process or store explosive, flammable, or toxic materials.

A more in-depth discussion of earthquake terminology and concepts is included in the Introduction of the Technical Analysis of this Element, along with a Glossary of Terms in the back of this Section (Appendix A).

B. TECHNICAL CONCLUSIONS

One of the principal objectives of the Seismic Safety Element is to identify and evaluate the different types of seismic hazards. These analyses are found in the Technical Analysis and form the basis for the recommended goals and policies of the Element. Major conclusions from the technical analysis are as follows:

1. The City of San Luis Obispo is located in a seismically active area.

2. The states of activity of the major faults affecting San Luis Obispo have been evaluated using available detailed mapping supplemented by local field examinations and aerial photo study. Major conclusions are:

   a) The San Andreas fault is active, and is expected to be the source of a magnitude 8.0 - 8.5 earthquake in the near future. This earthquake would be accompanied by 20 - 30 feet of ground displacement.

   b) The Nacimiento fault is seismically active. Data is inadequate to determine the potential for future ground rupture.

c) The Rinconada fault is seismically active, but probably will not be the site of ground rupture in the near future. Data is inconclusive on the latter point, and additional studies would be advisable.

d) The Offshore fault is seismically active, but available marine geophysical data indicate future surface rupture is very probable.

e) The San Juan, La Panza, East Huasna, West Huasna, Edna, Indian Knob, San Miguelito, and Edna extended (?) faults are probably inactive.

3. No active or potentially active faults are known to be present within or near the vicinity of San Luis Obispo.

4. Surface rupture resulting from fault movement is not considered a problem within the City.

5. The primary source of strong ground shaking in San Luis Obispo is expected to be the San Andreas fault. An earthquake of Richter magnitude 8.0 to 8.5 is expected in the near future.

6. The Nacimiento fault is considered a secondary source of strong ground shaking, but would have negligible effect on San Luis Obispo.

7. Shaking from earthquakes expected on the Rinconada and Offshore faults would not significiantly override the severity of shaking expected from the San Andreas fault in the San Luis Obispo area.

8. Recent alluvium in Los Osos Valley, particularly in the vicinity of Laguna Lake, should be considered hazardous with respect to settlement and liquefaction potential.

9. Landslides are common in the rocks which underlie the hills surrounding the City, and landsliding is considered a significant hazard in portions of the San Luis Obispo area. A summary of landslide risk is presented on the Seismic Zones Map (in the pocket at the back of the report).

10. The effects of seiching (oscillating waves in enclosed bodies of water) within storage tanks may be significant and should be evaluated by a qualified structural engineer.

11. Tsunamis (seismic sea-waves, or "tidal waves") are not considered a significant hazard in San Luis Obispo.

## C. HAZARD DELINEATION

The areal distribution of seismic hazards in the City of San Luis Obispo are shown on the Seismic Zones Map. Detailed discussions of the analyses of these hazards are contained in the Technical Analysis. A brief explanation is provided here as background for the recommended policies, and as an aid in interpreting the Seismic Zones Map.

The primary seismic hazard of most concern to the City of San Luis Obispo is ground shaking, which is described on the map in terms of seismic zones.

These zones were derived through an analysis of the variation in underlying geologic formations and distance from the San Andreas fault zone.

The seismic zones are expressive of the level of ground motion that can reasonably be anticipated from earthquakes on the principal fault system, the San Andreas, affecting the City of San Luis Obispo. The characteristics of each seismic zone are represented by response spectra which translate ground motion into displacement (inches); velocity (inches per second); and acceleration (inches per second per second) expressed as a percentage of the acceleration of gravity. These three factors, which are derived from mathematical analysis, essentially describe each seismic zone. These are the engineering "tools" for use in designing structures. Specific values for these ground motion factors are contained in the response spectra graphs for each seismic zone (Technical Analysis pp. 2.4-2.5). Generalized characteristics for each seismic zone are contained in Table 2 of the Technical Analysis.

In general, the following statements can be made regarding the seismic zones within the study area:

1. The seismic zones have been derived from two basic sets of criteria: (a) distance from the source of an earthquake; and (b) geographical differentiation of soil and bedrock conditions. The distances from the San Andreas fault range from 38 to 43 miles in the City. Since the variation in ground shaking will not be significant over this range, the distances from the fault to various areas of the City are not differentiated. An average of 40 miles is used in the analyses for the expected magnitude 8.0 - 8.5 event on the San Andreas fault. Variations among soil and bedrock types are expressed in alphabetical form on the map, and constitute the different seismic zones.
2. The seismic zone analysis is based upon the San Andreas fault system as the principal source of strong shaking.
3. Soil and bedrock conditions within the study area have been differentiated into six significant types as follows:

   Zone F - all areas immediately underlain by Franciscan Formation bedrock
   Zone K - all areas immediately underlain by Cretaceous sedimentary rocks
   Zone T - all areas immediately underlain by Tertiary sediments
   Zone P - all areas immediately underlain by Paso Robles Formation
   Zone Q - all areas immediately underlain by Quarternary Terrace deposits
   Zone R - all areas immediately underlain by recent alluvial sediments. The subscript "L" in the vicinity of Laguna Lake designates an alluvial area of significant liquefaction hazard and does not pertain to ground shaking

The secondary seismic hazards of liquefaction and settlement are significant over a large area on the Seismic Zones Map. The following is a generalized guide to settlement/liquefaction potential intended for use by soils engineers.

| Units on Seismic Zones Map | Material | Settlement/Liquefaction Potential |
|---|---|---|
| F, K, T | Bedrock | Very Low |
| P, Q | Paso Robles Formation, Terrace Deposits | Low to Moderate |
| R | Recent alluvium | High |
| $R_L$ | Recent alluvium in the Laguna Lake area | High+ |

The assessment of landslide risk delineated on the Seismic Zones Map is based on empirical relationships between known landslides in areas of detailed mapping and controlling factors such as rock material and structure, rainfall and slope. A summary of landslide risk is presented below.

| Units on Seismic Zones Map | Material | Landslide Risk |
|---|---|---|
| F | Franciscan Formation | Very High |
| K | Cretaceous Sediments | Moderate |
| T | Tertiary Sediments | High |
| P, Q | Paso Robles Formation Terrace deposits | Low |
| R, $R_L$ | Recent alluvium | Negligible |

D. RISK

The Council on Intergovernmental Relations (CIR) defines "Risk" from natural and man-made hazards in three categories:

1. Acceptable Risk: The level of risk below which no specification by government is deemed to be necessary.
2. Unacceptable Risk: The level of risk above which specification by government is deemed to be necessary to protect life and property.
3. Avoidable Risk: A risk which need not be taken because individual or public goals can be achieved at the same, or less, total "cost" by other means without taking the risk.

Determining levels of appropriate or acceptable risk is a multi-disciplinary process which relies heavily on citizen input. There is no such thing as a perfectly hazard-free environment. Natural and man-made hazards of some kind are always present, especially in urban areas. However, effective loss-reduction measures can be used in mitigating the consequences of known hazards. The determination of acceptable risk involves making a judgement about risk, either explicit or implicit, which is a necessary step in planning for loss-reduction from natural hazards.

The central concept used in determining acceptable risk is the definition of natural events in terms of magnitude and frequency. The magnitude of an event refers to its size. Examples are the height of flood waters, the rating of an earthquake on the Richter scale, or the number of acres burned in a wildland fire. The frequency of an event refers to the

number of times it occurs during a certain period of time. The relationship between magnitude and frequency is inverse. That is, the less often an event occurs, the greater is its size and potential impact. For example, rainstorms occur annually in the City of San Luis Obispo, but most often they are of low magnitude and do not seriously threaten the City. However, on relatively infrequent occasions, as in January of 1973, a storm of great magnitude will pass over the City and result in destructive flooding. A way of summarizing this concept with respect to an earthquake is that the longer it waits, the bigger it will be. [1]

The magnitude-frequency concept is involved in the decisions regarding acceptable risk in that the community must judge what magnitude event should be planned for. That judgment is based on the frequency or response interval of the hazardous event. A description of the magnitude and other characteristics of the event are then developed through a technical analysis. This information allows planners and engineers to develop loss-reduction measures and to design structures to provide protection up to the level of acceptable risk. In this sense, the magnitude earthquake used in defining acceptable risk may be thought of as a "design earthquake".

[1] There is one important difference between flooding and earthquakes, however. Flooding is the result of a random combination of meteorological events, whereas current geologic theory indicates that the buildup of strain along a particular fault system is nearly constant and the periodic release of that strain in the form of an earthquake is apt to be regular.

The determination of acceptable risk from hazardous events also involves differentiating among man-made structures according to their potential effect on the loss of life and their importance in terms of emergency response and continued community functioning. In the hours immediately following the 1971 San Fernando earthquake in Southern California, emergency services were impaired by damage to police and fire stations, communication networks, and utility lines. Several hospitals were seriously damaged and unable to continue functioning. These facilities and others are vital to the community's ability to respond to a major disaster and to minimize loss of life and property. The experience in San Fernando emphasized the need to provide these "critical facilities" a higher level of protection from earthquakes than limited, or normal occupancy structures, or other non-critical structures. As a minimum, all structures which could have an effect on the loss of life should be designed to remain standing in the event of a major earthquake even if rendered useless. Critical facilities, on the other hand, should not only remain standing, but should be able to operate at peak efficiency in the event of a disaster. The taxonomy of Critical Facilities presented in Table 1 is intended for use as a guide in evaluating the importance of each facility relative to overall public safety in terms of seismic hazards. The public must decide what specific types of land use would fall under the classifications "critical" or "normal".

Based on the discussion above and on input from the City Council and Planning Commission in the City of San Luis Obispo, the expected 8.0-8.5 magnitude event is recommended

TABLE 1

TAXONOMY OF CRITICAL FACILITIES

| Land Use/Facility | Safety Characteristic | | | Classification | |
|---|---|---|---|---|---|
| | Potential Effect on Loss of Life | Emergency Response | Vital Function | Critical | Normal |
| <u>Developed Land</u> | | | | | |
| RESIDENTIAL | | | | | |
| - Single Family | | | | | X |
| - Multi-family and Mobile homes | | | | | X |
| - Apartments | | | | | X |
| COMMERCIAL | | | | | |
| - Neighborhood Centers (e.g., grocery, barber, drug store) | | | | | X |
| - Community Centers (e.g., private offices, banks, restaurants, comparison shopping) | | | | | X |
| - Highway Centers (e.g., motels, fast food, restaurants) | | | | | X |
| - Heavy Commercial/Light Industry (e.g., contractors yards, distribution warehouses, manufacturing and assembly plants) | | | | | X |
| - Heavy Industry | | | | | X |
| <u>Developed Land</u> | | | | | |
| PUBLIC AND SEMI-PUBLIC USES | | | | | |
| - Hospitals | | X | X | X | |
| - Schools/Colleges | X | | | X | |
| - Parks and Recreation Areas | | | | | X |
| - Government Facilities (e.g., civil defense quarters, fire and police stations, government offices) | | X | X | X | |
| - Utilities (e.g., power plants (nuclear fossil fuel) gas and electric lines and stations, large dams, radio/TV/microwave centers and lines, aqueducts, pipelines, sewage treatment facilities, gas stations, waterworks) | | X | X | X | |
| - Roads and Highways | | X | X | X | |
| - Railroads | | | X | X | |
| - Airports | | | X | X | |
| - Assembly Halls (e.g., theaters, auditoriums) | X | | | X | |
| - Refuse Disposal Sites | | | | | X |
| - Cemeteries | | | | | X |
| <u>Undeveloped Land</u> | | | | | |
| - Agriculture | | | | | X |

as the basis for establishing earthquake design standards. These standards, based on modifications of the Uniform Building Code Earthquake Regulations, should reflect the recommendations that (1) normal facilities remain standing, and (2) critical facilities continue to function at peak efficiency in the event of an 8.0-8.5 earthquake on the San Andreas fault.

# III. HAZARD REDUCTION

## A. ORGANIZATION AND PURPOSE OF RECOMMENDATIONS

The previous section of this document presents a synthesis of the existing seismic hazards within the San Luis Obispo study area, and provides a set of planning and design criteria documented in the Technical Analysis of the Element. The intent of that section is to summarize the general framework within which planning for seismic safety should take place. In this section, recommendations are presented which encompass the general planning goals and policies for hazard reduction in the City of San Luis Obispo. This section also outlines specific recommended planning actions to implement the Element's goals and policies.

## B. GOAL RECOMMENDATIONS

To plan effectively for reducing hazards to acceptable levels of risk, it is necessary that goals be set and adhered to. Goals address general policy directions which form the basis for planning decisions and actions. The recommended goals for hazard reduction in the City of San Luis Obispo are:

1. To minimize injury and loss of life from seismic hazards.
2. To minimize damage to public and private property resulting from seismic hazards.
3. To minimize social and economic dislocations resulting from injury, loss of life, and property damage caused by seismic events.

## C. POLICY RECOMMENDATIONS

The following recommended policies complement the planning goals and define specific direction for the City to take in reducing seismic hazards.

1.0 Adopt new ordinances and amend existing ordinances which require the incorporation of seismic safety considerations in developments under the City's jurisdiction.

2.0 Provide for the identification and evaluation of existing structural hazards.

3.0 Risks associated with hazardous structures should be reduced to acceptable levels through orderly hazard reduction programs.

4.0 Provide for more detailed scientific analyses of seismic hazards in the study area.

5.0 Regulate land use in areas of significant seismic hazard.

6.0 Provide for the education of the community regarding the nature and extent of earthquake hazards in the study area.

7.0 Provide for the maintenance and upgrading of disaster response plans.

8.0 Provide for review and upgrading of the Seismic Safety Element.

## D. IMPLEMENTATION RECOMMENDATIONS

The implementation recommendations in this section are intended to provide the City with a series of specific planning actions to achieve the goals of these Elements and carry out the policies recommended above. While it would be advisable to fully implement each of the recommended actions, it is recognized that unlimited resources to that end are not available. These recommended actions should be thought of, then, as options to be implemented as resources provide. To aid in determining priorities for the allocation of resources in the community, the recommended policies and actions are listed below in their general order of importance to achieving the goals of the Element.

1.0 <u>Adopt new ordinances and amend existing ordinances which require the incorporation of seismic safety and safety consideration in developments under the City's jurisdiction</u>

- 1.1 Adopt the 1973 Uniform Building Code.
- 1.2 Using the geological data provided in the Seismic Safety Element, amend Chapter 23, Section 2314, (Earthquake Regulations) of the Uniform Building Code to account for the expected maximum ground accelerations of the recommended design earthquakes. Amending Section 2314 involves revising the basic lateral force equation in the section, and requires analysis by a qualified structural engineer. The intent of the revisions is to reflect the levels of acceptable risk adopted in this Element. The recommended acceptable risk policy states that non-critical facilities should be designed to remain standing in the event of an 8.5 magnitude earthquake on the San Andreas fault. Critical facilities should be designed to function at peak efficiency after an 8.5 magnitude earthquake on the San Andreas.[2]
- 1.3 Amend Chapter 70, Section 7006, of the Uniform Building Code to require soils engineering and geological engineering investigations in areas of moderate, high, and very high landslide risk and in areas of high and high+ liquefaction potential and subsidence potential. To insure adequate review and use of the investigation reports, the City should retain a qualified engineering geologist on a full or part-time basis to review the reports and assist the Community Development Department in designing public projects.

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[2]At this time, proposed revisions to Section 2314 are being considered by the International Conference of Building Officials for adoption in the 1976 UBC. The proposed revisions would significantly increase the minimum lateral force requirements, and could, if adopted, reduce the extent of revision necessary to amend the Code in conformance with expected seismic events in San Luis Obispo.

2.0 <u>Provide for the identification and evaluation of existing structural hazards</u>

2.1 It is recommended that structures within the study area of this report be inspected for conformance with the amended Uniform Building Code earthquake regulations. Inspections should be conducted according to the following priorities:

(a) emergency service facilities (e.g. fire and police stations, hospitals)

(b) other critical facilities (e.g. schools, utility lines, government buildings)

(c) high occupancy non-critical facilities (e.g. dormitories, apartments)

(d) normal or limited occupancy non-critical facilities (offices, low density residential buildings)

Within each priority group, it is recommended that facilities built before 1933 be inspected first, then those built between 1933 and 1948, and lastly, those constructed after 1948. The significance of the year 1933 is that the Field and Riley Acts became law in California that year and required reinforcement in schools and certain other structures (Appendix B). Structures built before 1933, especially larger commercial structures, are more likely to be unreinforced masonry block buildings which are more susceptible to collapse in earthquakes. In 1948, earthquake regulations were adopted as a legally binding section of the UBC for the first time. Previously, earthquake standards were set forth in the Appendix of the UBC and were not a mandated part of the Code. It is more likely, then, that a building constructed before 1948 would be less able to withstand the shock of an earthquake than one built after 1948. It is also recommended that public structures be inspected before private structures.

Table 2 (abridged from Pacific Fire Rating Bureau) may be used as a general indicator in older construction for use in establishing a priority ranking system for evaluating structures. Buildings with a high susceptibility to damage rating (five or over) should be selected for structural inspection before those with low ratings. A high priority should be placed on establishing a definition of facilities that handle explosive, flammable, or toxic materials and on an evaluation of their seismic vulnerability.

2.2 Caltrans should review its facilities and roadways within the study area to determine the potential impact of expected earthquakes, and should forward comments to the City. The Circulation Element of the General Plan and potential evacuation routes should be revised, if necessary.

2.3 Southern Pacific Railroad Company should review its lines and yards within the study area to determine the potential impact of the expected

TABLE 2
HAZARD COMPARISON OF NON-EARTHQUAKE-RESISTIVE BUILDINGS

| Simplified Description of Structural Type | Relative Damagability (in order of increasing susceptibility to damage) |
|---|---|
| Small wood-frame structures, i.e. dwellings not over 3,000 sq. ft. and not over 3 stories | 1 |
| Single or multistory steel-frame buildings with concrete exterior walls, concrete floors, and concrete roof. Moderate wall openings | 1.5 |
| Single or multistory reinforced-concrete buildings with concrete exterior walls, concrete walls, and concrete roof. Moderate wall openings | 2 |
| Large area wood-frame buildings and other wood frame buildings | 3 to 4 |
| Single or multistory steel-frame buildings with unreinforced masonry exterior wall panels; concrete floors and concrete roof | 4 |
| Single or multistory reinforced-concrete frame buildings with unreinforced masonry exterior wall panels, concrete floors and concrete roof | 5 |
| Reinforced concrete bearing walls with supported floors and roof of any material (usually wood) | 5 |
| Buildings with unreinforced brick masonry having sand-line mortar; and with supported floors and roof of any material (usually wood) | 7 up |
| Bearing walls of unreinforced adobe, unreinforced hollow concrete block, or unreinforced hollow clay tile | Collapse hazard in moderate shocks |

This table is intended for buildings not containing earthquake bracing, and in general, is applicable to most older construction. Unfavorable foundation conditions and/or dangerous roof tanks can increase the earthquake hazard greatly.

earthquakes, and should forward comments to the City. The Circulation Element of the General Plan and potential evacuation routes should be revised, if necessary.

2.4 The Pacific Gas and Electric Company should review its facilities and distribution/transformation networks and centers to determine the potential impact of expected earthquakes, and should forward comments to the City.

2.5 The Ernest R. Righetti Dam should be inspected using the seismic response spectra as guidelines to determine the structure's ability to withstand expected earthquakes, and the City should be advised of the results of the investigation.

3.0 <u>Risks associated with hazardous structures should be reduced to acceptable levels through orderly hazard reduction programs</u>

3.1 Structures identified as not conforming to amended earthquake standards should be brought into conformance with acceptable levels of risk by programs including, but not limited to, structural rehabilitation, occupancy reduction, and demolition and reconstruction.

3.2 A review committee should be established by the City Council to consider the desirability of initiating the condemnation proceedings against structures found to be unsafe.

3.3 The City should advocate the expansion of State and Federal relocation assistance funds and programs to aid persons and businesses displaced from hazardous buildings.

4.0 <u>Provide for more detailed scientific analyses of natural hazards in the study area</u>

4.1 Provide for a detailed field study of the potential for liquefaction in all areas underlain by recent alluvial deposits.

4.2 Require site-by-site soils and geologic engineering studies for proposed development projects in areas of moderate, high, and very high landslide risk to assess natural and graded slope stability. Slope stability calculations should incorporate the ground shaking parameters presented in the Technical Section.

4.3 Require site-by-site soils and geologic engineering studies in areas of high and high+ potential liquefaction and settlement and evaluate these potential hazards using the ground shaking parameters presented in the Technical Analysis.

4.4 Require investigations of proposed graded slopes within the study area using the seismic parameters presented in the Technical Analysis to assess their stability.

4.5 Institute a building strong-motion instrumentation program for buildings over four (4) stories in height, if such buildings are anticipated.

4.6 Provide for a detailed geologic study of the Ernest R. Righetti Reservoir with emphasis on the stability of slopes surrounding the Reservoir.

5.0 <u>Regulate land use in areas of significant natural hazard</u>

5.1 No development should be permitted in any seismic zone unless it conforms to the recommended revised Uniform Building Code Earthquake Regulations.

5.2 No development should be permitted in areas of moderate, high, or very high landslide risk without requiring a slope stability investigation in the vicinity of the site.

5.3 No critical facilities should be permitted in the area of high+ potential liquefaction. No facilities should be permitted in areas of high and high+ liquefaction potential without requiring a detailed site investigation which addresses the specific potentials for liquefaction and settlement.

6.0 <u>Provide for the education of the community regarding the nature and extent of natural hazards in the study area</u>

6.1 Develop an information release program to familiarize the citizens of region with the Seismic Safety Element. Special attention should be afforded to those groups particularly susceptible to seismic hazards including, but not limited to, school districts, agencies involved with the aged, and agencies involved with handicapped persons. These agencies should be encouraged to develop educational programs of their own relative to hazard awareness. The conclusions and recommendations of these elements should also be provided to land developers and those involved in the real estate profession. Appendix C provides a list of earthquake safety procedures.

6.2 Establish community programs that train volunteers to assist police, fire, and civil defense personnel during and after a major earthquake.

7.0 <u>Provide for the maintenance and upgrading of disaster response plans</u>

7.1 Maintain the City of San Luis Obispo Civil Defense and Disaster Emergency Plan. Objectives of the program should be:

(a) To save lives and protect property

(b) To provide a basis for direction and control of emergency operations

(c) To provide for the continuity of government

(d) To repair and restore essential systems and services (eg. emergency water supplies)

(e) To provide for the protection, use and distribution of remaining resources

(f) To coordinate operations with the civil defense emergency operations or other jurisdictions

(g) To provide for a maximum degree of self-sufficiency by the City in the event of a major disaster

Since a large earthquake will severely affect many cities and hundreds of thousands of people, the efforts of the Federal and State emergency services will be severely over-extended. It is advisable that the City of San Luis Obispo be prepared to serve itself and maintain continued functioning of necessary services rather than expect adequate aid from outside organizations. At the time of review, the Emergency Plan should be revised to account for this effect of expected earthquakes.

7.2 Conduct periodic earthquake emergency drills. These drills should be coordinated on a regional basis in cooperation with all involved jurisdictions.

8.0 <u>Provide for review and upgrading of the Seismic Safety Element</u>

8.1 Upon adoption of the Seismic Safety Element, a review committee should be established to oversee the implementation of the Element and to advise the City Council of implementation progress. This committee should be composed of the Director of Community Development, the City Engineer, and at least one representative from each of the police and fire protection service agencies.

8.2 The Seismic Safety Element should be reviewed by the Department of Community Development annually and should be comprehensively revised every five years or whenever substantially new scientific evidence becomes available.

# IV. RELATIONSHIPS TO OTHER GENERAL PLAN ELEMENTS

The Seismic Safety Element is the major geological hazards analysis in the General Plan and, as such, has important policy implications for other elements in the Plan. In particular, the Seismic Safety Element provides significant information for the Land Use, Housing, Open Space, and Circulation Elements. It is recommended that these Elements be prepared or revised to give specific recognition to the policies adopted in the Seismic Safety Element.

The Land Use Element will be influenced most directly by the recommendations of Policy 5.0 to regulate land use in areas of significant natural hazard. The Land Use Element may also recommend land use controls for those areas in which "stacking" or combinations of individual hazard zones result in a high level of overall hazard. Figure 2 is provided as an aid in evaluating the effects of "stacking" on various land uses.

The policies of this Element provide input to the Housing Element primarily by recommending design and construction modifications. The following recommendations pertain directly to the Housing Element:

1. All new construction should conform to the revised Uniform Building Code Earthquake Regulations.
2. Existing high occupancy residential structures found to be seismically vulnerable should be strengthened or replaced or their occupancy level should be reduced.

The Seismic Safety Element identifies certain areas which should be considered for open space designation as part of the Open Space Element. These areas include lands designated as high and very high landslide risk areas and areas of high and high+ liquefaction potential.

The Circulation Element should recognize that the transportation network in San Luis Obispo will be hard hit in the event of a major earthquake. An earthquake will affect primarily freeway overpasses, road bridges, and railroad grade crossings. The effects expected will be similar to what occurred in the Sylmar-San Fernando Valley area of Southern California in the 1971 earthquake. The response spectra presented in the Technical Analysis of the Seismic Safety Element should be used by structural engineers in the evaluation of existing freeway overpasses and other important grade separations. New construction of bridges, overpasses, and other grade crossings should also utilize seismic response design criteria.

Figure 2. LAND USE POLICY SUMMARY

| LAND USE/FACILITY | | PRIMARY AND SECONDARY HAZARD ZONES | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 1/ F | K | T | P | Q | R | $R_L$ | 2/ VH | H | M | L | N | 3/ H+ | H | M | L | VL |
| CRITICAL | Hospitals, Schools/Colleges, Government Facilities, Utilities, Roads and Highways, Railroads, Airports, Assembly Halls | ○ | ○ | ○ | ○ | ⊘ | ⊘ | ⊘ | ⊘ | ⊘ | ⊘ | ○ | ○ | ● | ⊘ | ○ | ○ | ○ |
| NORMAL | Single Family Residences, Multi-family Residences, Apartments, Neighborhood Commercial Centers, Community Commercial Centers, Highway Commercial Centers, Heavy Commercial/Light Industry, Heavy Industry, Parks and Recreation Areas, Refuse Disposal Sites, Cemeteries, Agriculture | ○ | ○ | ○ | ○ | ○ | ⊘ | ⊘ | ⊘ | ⊘ | ⊘ | ○ | ○ | ⊘ | ⊘ | ○ | ○ | ○ |

EXPLANATION

1/ Ground shaking zones

2/ Landslide risk zones

3/ Liquefaction potential zones

○ Suitable for development

⊘ Provisionally suitable for development with detailed study/hazard mitigation

● Unsuitable for development

# PART 2: TECHNICAL ANALYSIS

# PREFACE

The following Technical Analysis is a condensation of the more detailed Technical Report prepared by Envicom Corporation (1974) for the San Luis Obispo County Seismic Safety Element. The intent of this Technical Analysis is not to present a dissertation on primary and secondary seismic hazards in the study area, since these hazards are generic to the entire County and have been fully discussed in the County Seismic Safety Element. Instead, the intent of the Technical Analysis is to present the geological information pertinent to the City of San Luis Obispo which provides the framework for planning decision-making. References for this analysis are contained in the County Seismic Safety Element.

# I. SUMMARY OF PRIMARY HAZARDS

## A. GEOLOGIC SETTING

The City of San Luis Obispo is located in one of the most complex geologic provinces in California. The hills surrounding the City are predominately underlain by metamorphic rocks of the Mesozoic-age Franciscan Formation. Sedimentary rocks of Cretaceous and Tertiary ages unconformably overlie the Franciscan and are present in portions of the hills to the north and south of San Luis Obispo. Tertiary-age intrusive igneous rocks are found locally within the Franciscan Formation and stand out conspicuously as steep flanked knobs, notably, Bishop Peak, Cérro San Luis Obispo, and Islay Hill.

The low-lying valley areas are predominantly underlain by varying thicknesses of Recent-age alluvium. Nonmarine sediments of the Paso Robles Formation and local river terraces are present locally south of San Luis Obispo.

## B. ACTIVITY OF FAULTS

Active and potentially active faults in the region have been identified as a part of the investigation for the Seismic Safety Element for the County of San Luis Obispo (Envicom, 1974), and no active or potentially active faults are known to be present within the study area. The major fault 16 miles offshore, and the Rinconada fault, 8 miles to the northeast, are considered seismically active, but there is no evidence that either fault has moved at the surface in the past 11,000 years. Therefore, neither fault should be considered as "active" within the definitions and policies established by the State Geologist and the State Mining and Geology Board. The seismic activity of these two faults has involved scattered small earthquakes with the energy release taking place at depth (Envicom, 1974). The effect of this seismicity is such that it should not exceed the effect of the major earthquake expected on the San Andreas fault.

Both the Edna and West Huasna faults traverse the study area as shown on the Seismic Zones Map. Data compiled in the County Seismic Safety Element indicate that, at this time, there is not sufficient evidence of either tectonic or seismic activity on either of these faults in the past 11,000 years. The risk of a significant earthquake occurring on either the Edna or West Huasua faults is too remote to be expanded upon further.

## C. EARTHQUAKE SHAKING

The analysis of known active faults in the region indicate that the most probable source of strong shaking in the San Luis Obispo area will be an earthquake of Richter magnitude 8.0-8.5 on the San Andreas fault approximately 40 miles to the northeast. San Luis Obispo is located in distance Zone 1 of the County Seismic Safety Element which is the zone most distant from the fault, and thus the one which will experience the mildest shaking relative to other zones in the County.

The intensity of ground shaking will vary across the study area depending on the rock/soil types present. Six general rock/soil types are present within the study area. These are delineated on the Seismic Zones Map and summarized below:

- F - Franciscan Formation and associated Miocene-age igneous intrusives.
- K - Cretaceous-age sedimentary rocks.
- T - Tertiary-age sedimentary rocks.
- P - Plio-Pleistocene-age Paso Robles Formation.
- Q - Quaternary-age terrace deposits.
- R - Recent-age alluvial deposits.

The subscript "L" in the Laguna Lake area refers to liquefaction and settlement and is not applicable to the ground shaking analysis.

The response spectra for Zones F and K, T and P and Q are shown in Figures 1, 2, and 3, respectively. Modifications to be applied to Figure 1 for the response spectra of Zone R will depend on the thickness of the alluvium at a particular site. Table 1 presents amplification factors, and the period range over which they apply, for various alluvial thicknesses. Table 2 presents generalized characteristics of ground shaking expected from the earthquake on the San Andreas fault in the Zones discussed above.

TABLE 1

AMPLIFICATION CHARACTERISTICS FOR ZONE R

| Thickness of Alluvium (feet) | Amplification Factor | Period Range (seconds) |
|---|---|---|
| 15 | 3 | 0-0.1 |
| 40 | 3 | 0-0.2 |
| 70 | 3 | 0.1-0.3 |
| 150 | 3 | 0.2-0.5 |

TABLE 2

GENERALIZED GROUND-SHAKING CHARACTERISTICS BASED ON A MAGNITUDE 8.5 EARTHQUAKE ON THE SAN ANDREAS FAULT

| Characteristics | Zones F & K | Zones T | Zones P & Q | Zones R |
|---|---|---|---|---|
| Maximum Ground Acceleration (gravity) | 0.07 | 0.08 | 0.15 | 0.2-0.25 |
| Predominant Period (seconds) | 0.2-0.4 | 0.4-0.6 | 0.3-0.5 | 0.2-0.5 |
| Duration of Strong Shaking (seconds) | 30-40 | 30-40 | 40-50 | 40-60 |
| Spectra | Fig. 1 | Fig. 2 | Fig. 3 | Modification of Fig. 1 using Table 2. |

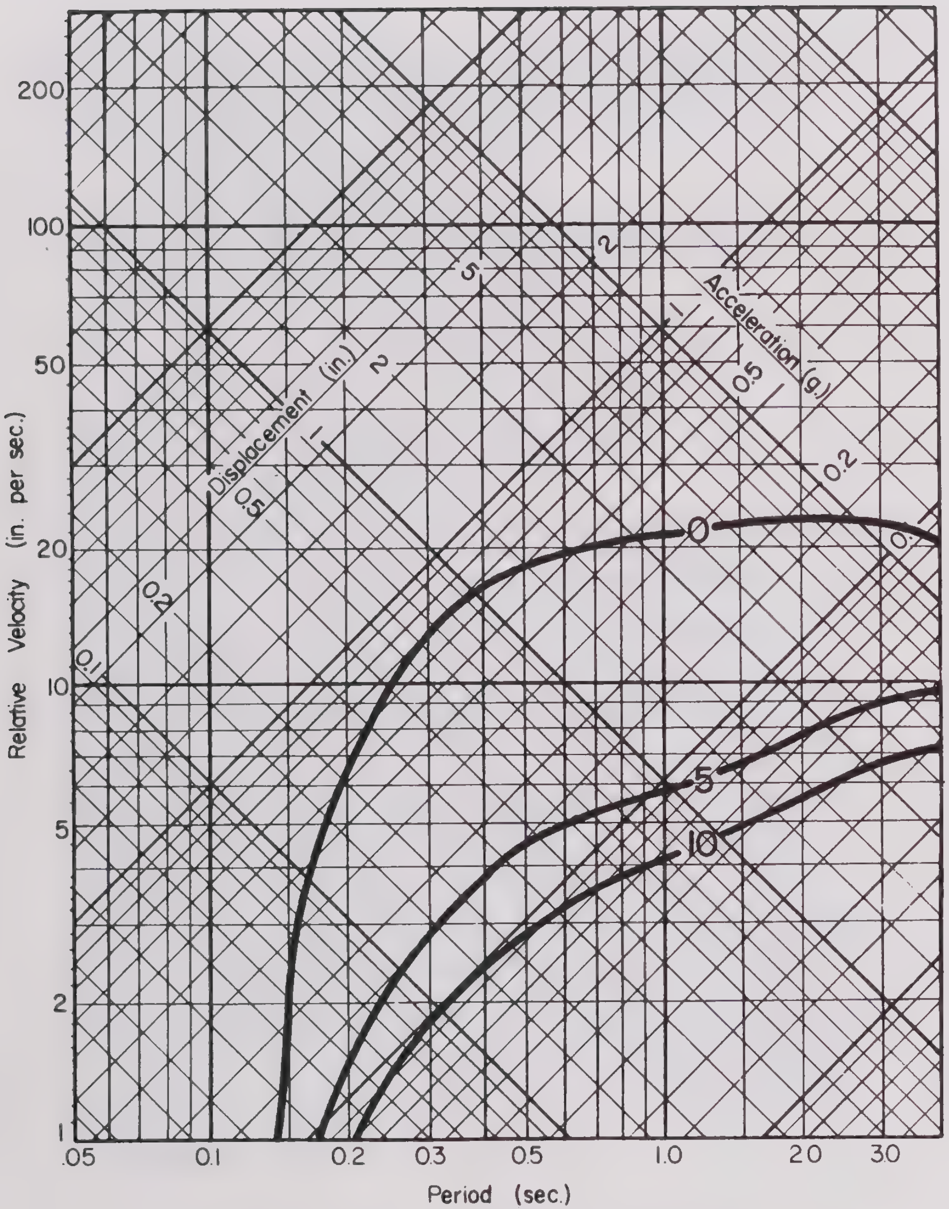


Figure 1. Response spectra for magnitude 8.5 earthquake on San Andreas fault for Zones F, K, and R and 0, 5, and 10% critical damping.

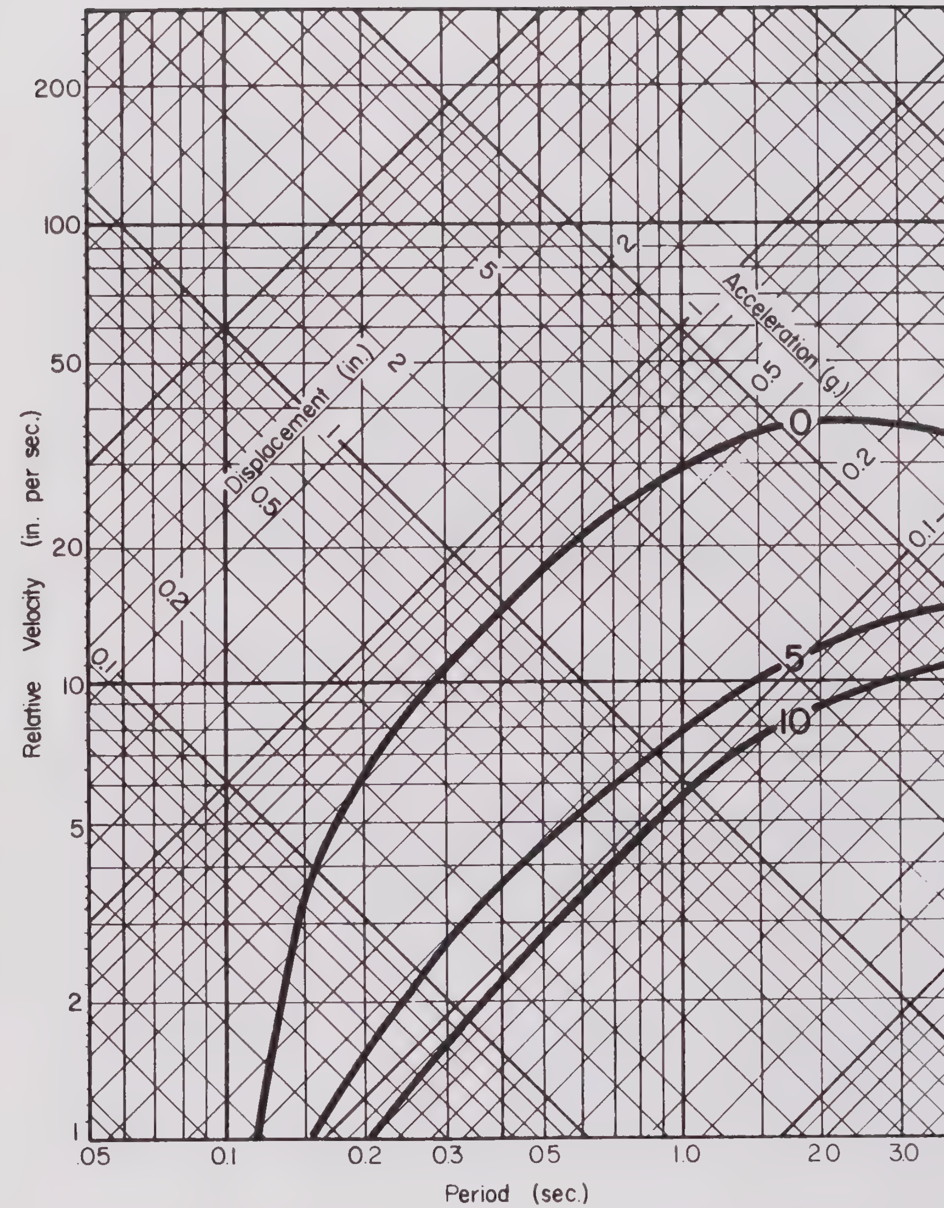


Figure 2. Response spectra for magnitude 8.5 earthquake on San Andreas fault for Zone T and 0, 5, and 10% critical damping.

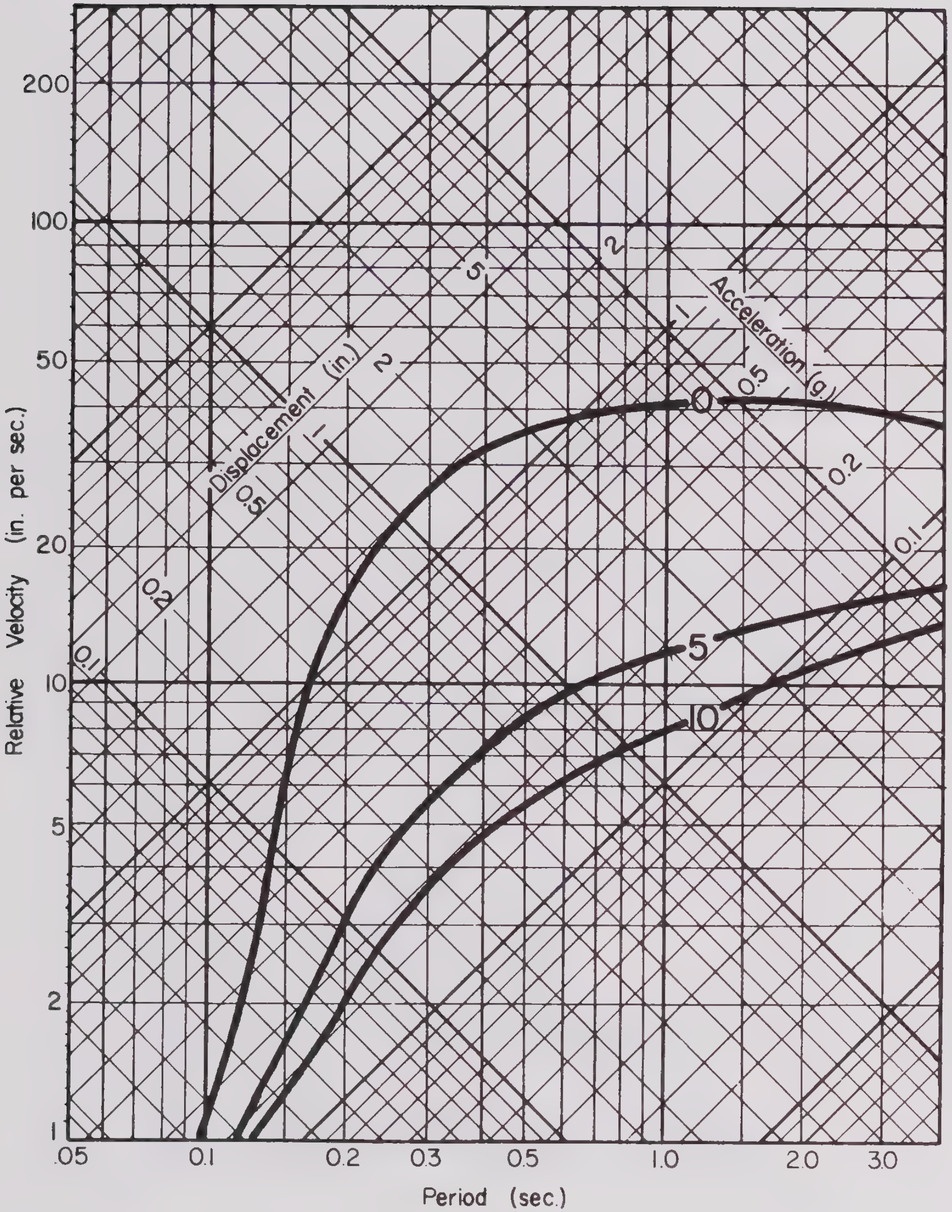


Figure 3. Response spectra for magnitude 8.5 earthquake on San Andreas fault for Zones P and Q and 0, 5, and 10% critical damping.

# II. SUMMARY OF SECONDARY HAZARDS

A. LANDSLIDES

1. Types of Landslides

Landslides represent only one step in the continuous, natural erosional process. They demonstrate, in a dramatic way, the tendency of natural processes to seek a condition of equilibrium. The steep slopes of mountainous and hillside terrains are not in a state a equilibrium, and various erosional processes act to gradually reduce them to base level. Landsliding is an important agent in this cycle.

Several types of landslides commonly encountered include:

1. Block glides (Figure 4) - These are the largest, most impressive type of slide. The basal failure plane is controlled by planar zones of weakness such as bedding planes, joint planes, or formational contacts. Block glides typically occur in layered rocks of sedimentary or metamorphic origin where lateral support is removed by erosion.

2. Arcuate failures (Figure 5) - Arcuate failures are common in massive, unstructured material with relatively little resistance to shearing. These materials include thick sections of clayey soil, and poorly compacted artificial fills. The zone of failure typically describes an arc rather than a plane, and the movement of the mass is partly rotational. Small arcuate failures, called slumps, are common along steep-banked streams, where the stream has cut through an existing soil zone.

3. Mudflows (Figure 6) - Mudflows involve very rapid downslope movement of saturated soil, sub-soil, and weathered bedrock. They originate in hillside areas where the soil horizon is well developed, but the soil has poor drainage characteristics. Large mudflows may have the energy to uproot trees and to carry along boulders several feet in diameter. Because of the speed with which they move, mudflows can be quite destructive, especially along the bottoms and at the mouths of canyons.

4. Rockfalls (Figure 7) - This phenomenon, much like an avalanche of loose rock, cascades down a steep slope, disturbing more material as it passes, becoming more widespread until it reaches the bottom of the slope. The large talus slopes common in the High Sierra country, are the debris deposited from rock falls. They are prevalent where natural slope gradients exceed 50%, and where natural weathering produces angular fragments of material with little soil cover.

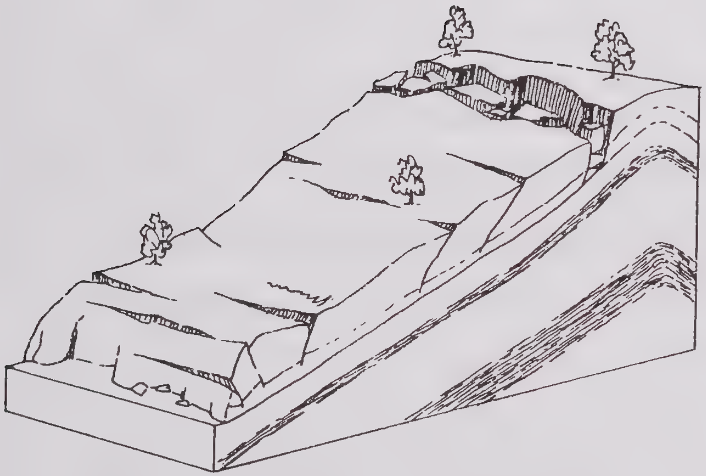

Figure 4. Block glide landslide

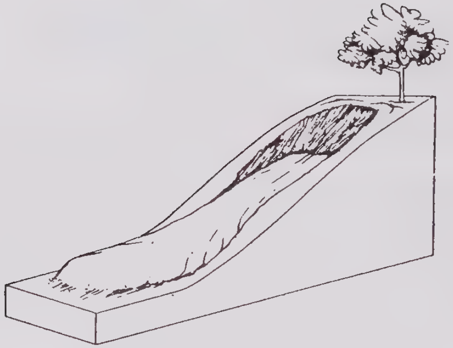

Figure 6. Mudflow

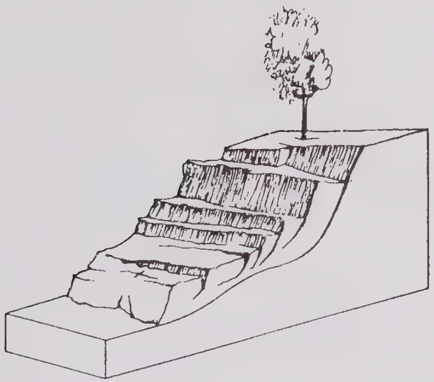

Figure 5. Arcuate failure or slump

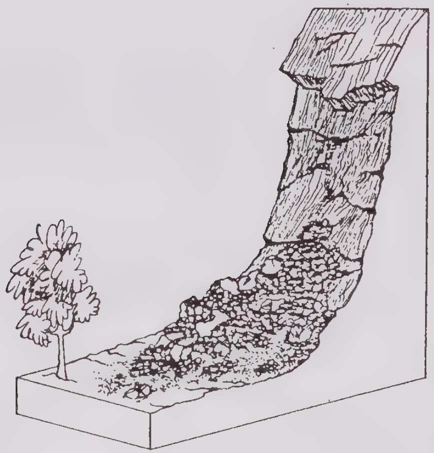

Figure 7. Rockfall

2. Controlling Factors

Landsliding is basically controlled by four factors. The rock type or geologic formation is a reasonably good indicator of the strength of the rock and its resistance to failure. The geologic structure or the orientation of potential failure planes is important in determining the size and type of failure. The amount of available water greatly influences the strength of a potential failure surface and also adds to the weight of the unstable mass, increasing the pressure and contributing to movement. Topographic slope is also a factor in controlling the force that causes failure. The relative importance of these four factors varies from place to place, but rock type, geologic structure, and available water are probably the most important. Some degree of slope is necessary to initiate failure, but if the other factors are present, failure can occur on slopes with a gradient of less than 5%.

3. Regional Setting

Landslides are common in the metamorphic Franciscan Formation and in the Tertiary sediments that underlie the hills surrounding San Luis Obispo. The serpentines and highly deformed melanges are particularly susceptible to sliding. Landslides mapped by Hall (1973) for the area south of $35^{o}22'30''$ North (Morro Bay Quadrangle) are shown on the Seismic Zones Map. Most of these slides are probably stable in their present condition, but the modification of conditions that often accompany development of such an area could result in reactivation of movement. Landslides shown in the remainder of the study area are based on the study of aerial photographs and limited field inspection.

4. Landslide Risk Appraisal

a. Methodology

The appraisal of landslide risk in San Luis Obispo takes into account the relationships discussed above, but is based primarily on empirical relationships. The landslides shown on the Seismic Zones Map are significant not only as individual areas of instability, but also as indications of the stability of the particular geologic units involved.

These empirical relationships between concentration of landslides and rock characteristics as expressed by the distribution of various geologic formations has been used to establish the landslide risk categories shown on the Seismic Zones Map.

b. Risk Categories

Areas having Negligible Risk rating include areas of low topographic relief such as alluvial valleys (Zones R & $R_L$). The areas are considered of negligible risk because of a lack of slope.

Areas assigned a Low Risk rating include the low-lying, incised terrace deposits (Zone Q), and the gently sloping areas of Paso Robles Formation (Zone P). Although not subject to massive failures, these deposits are prone to local slumping along stream channels.

Areas with a Moderate Risk rating are underlain by Cretaceous sediments (Zone K). These rocks are apparently less susceptible to sliding in their natural state than either the Franciscan Formation or Tertiary sediments since few slides were discerned in the analysis. However, the well-developed bedding in these rocks make them prone to failure if grading operations undercut existing bedding planes.

Areas having a High Risk rating include those underlain by Tertiary sediments (Zone T) These rocks exhibit well-developed bedding and complex folding, and typically occur in steep terrain.

Areas assigned a rating of Very High Risk are areas of moderate to steep terrain underlain by Franciscan Formation (Zone F). The Franciscan Formation is composed of incompetent material of complex structure. The majority of the massive landslides in the study area involve Franciscan Formation.

This evaluation is based primarily on natural conditions, and does not include an adjustment for change in stability that may accompany development. Such a change may occur due to the removal of impervious soils, removal of support by grading, and increased irrigation of crops or landscaping. Unknowns of this type serve to limit analysis of the type included here, and emphasize the need for competent soils engineering and engineering geologic evaluation of projects proposed in hillside terrains.

The risk appraisal is intended for use as a guide to land use planning and the administration of public safety, and should not be considered in any way as a substitute for the soils engineering and geologic evaluation of a specific project. Further evaluation of specific sites within the study area requires geologic and engineering data normally available only during the course of a detailed investigation of the site as well as knowledge of any modification of terrain that may be proposed for the site. This evaluation is best accomplished at the time a specific project is proposed.

c. Relationship of Earthquakes to Landslide

Landslides should be considered a basic geologic hazard rather than one peculiar to earthquakes. The shaking of an earthquake only provides the triggering force to initiate downslope movement of an already unstable earth mass. The prime factor is the unstable condition itself. Movement could just as easily be triggered by heavy rains or by grading on a construction project.

d. Landslide Generated Water Waves

Landsliding into lakes or reservoirs may generate large waves on the surface of the water that may do considerable damage to shore facilities, to the dam itself, or to areas downstream if the volume overtopping the dam is considerable. The potential hazard from landslide-induced water waves in San Luis Obispo is, therefore, related to the presence of any unstable land masses

on the slopes adjoining the reservoirs in the study area. The geologic conditions of the slopes descending into the Ernest R. Righetti reservoir in the east-central portion of the study area indicate the possible presence of at least one major landslide on the margin of the reservoir and a Very High risk of landslides on all of the slopes adjoining the reservoir and dam. No detailed geologic mapping or subsurface data is available for this area around the reservoir, but the risk from potentially damaging landslides is considered high enough to warrant a detailed investigation of the reservoir site.

## B. LIQUEFACTION

Liquefaction involves a sudden loss in strength of a saturated cohesionless soil (predominantly fine grained sand) which is caused by shock or strain (such as an earthquake), and results in temporary transformation of the soil to a fluid mass. If the liquefying layer is near the surface, the effects are much like that of quicksand on any structure located on it. If the layer is in the subsurface, it may provide a sliding surface for the material above it. Liquefaction typically occurs in areas where the groundwater is less than 30 feet from the surface and where the soils are composed of poorly consolidated fine to medium sand. In addition to the necessary soil conditions, the ground acceleration and duration of the earthquake must also be of a sufficient level to bring on liquefaction.

The potential for liquefaction varies considerably over the study area, dependent on the soil type and conditions. A meaningful determination of liquefaction potential requires data normally available only after a detailed investigation of a site. Only generalizations regarding liquefaction potential can be made at this time.

1. Rock materials (Zones F, K, and T on the Seismic Zones Map) have a very low to essentially non-existent potential for liquefaction.
2. The Paso Robles Formation and the terrace deposits (Zones P and Q) have a low to moderate potential for liquefaction.
3. Recent poorly consolidated alluvial deposits (Zone R) have a high potential for liquefaction since the limited groundwater information in the area suggests that the groundwater level is less than 30 feet from the surface over most of Zone R.
4. Zone $R_L$ is assigned a High+ rating to emphasize that this area is apparently more prone to liquefaction than the remainder of the R Zone, due to the presence of well stratified lake deposits and a perennial high water table.

The potential for liquefaction in the San Luis Obispo area must be considered for at least Zones R and $R_L$. It is not likely that the occurrence of liquefaction in this area from the expected earthquake on the San Andreas fault will be widespread, but will probably involve localized areas owing to the complexly stratified alluvial deposits.

Figure 8 presents a simplified evaluation of the liquefaction potential for Zones R and $R_L$ in the event of a magnitude 8.0 to 8.5 earthquake on the San Andreas fault.

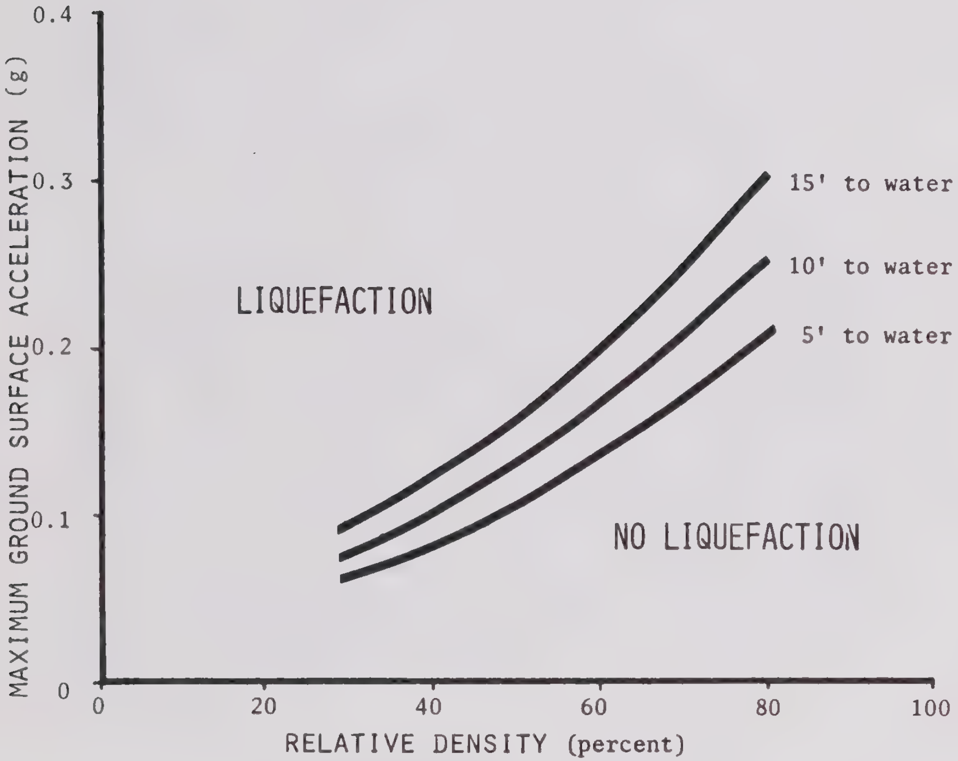


Figure 8. Liquefaction potential for earthquake of magnitude 8.0 to 8.5.

The four categories of liquefaction potential described above are generalizations intended to provide guidance in evaluating the need for addressing liquefaction in soils and engineering geologic reports. They should not be considered a substitute for the in-depth evaluation of a particular site.

In summary, Zones R and $R_L$ delineated on the Seismic Zones Map apparently contain some of the soil conditions necessary for liquefaction, and the expected ground shaking from the expected earthquake on the San Andreas fault, will probably provide the stresses necessary to initiate liquefaction. Detailed soils engineering and geology investigations will be necessary to further evaluate the potential for liquefaction, and to further define the affected areas.

## C. SETTLEMENT

Settlement may occur in unconsolidated soils during earthquakes shaking as the result of a more efficient rearrangement of the individual soil particles. Settlements of sufficient magnitude to cause significant structural damage are normally associated with rapidly deposited alluvial material, peat deposits, or improperly founded or poorly compacted fills. Our investigation identified no areas outside of the zones of potential liquefaction shown on the Seismic Zones Map, which would experience significant settlement during an earthquake.

## D. TSUNAMIS

Tsunamis are seismic sea waves generated primarily by vertical offsets of the sea floor accompanying submarine faulting. Their

damaging effects are confined to low-lying coastal areas. They will have no effect on San Luis Obispo.

## E. SEICHES

Seiches are standing waves produced in a body of water by winds, atmospheric changes, the passage of earthquake waves, etc. Studies of true seismic seiches are limited, but that by McGarr and Vorhis, 1968, of seiches induced by the Alaska earthquake of 1964 indicates that the largest recorded wave heights (double amplitude) did not exceed 1.2 feet. Since this is less than wave heights that would be expected from wind-induced waves, true seismic seiches are not considered as constituting a significant hazard in open bodies of water in the study area. However, seiching may be more important in storage tanks within the San Luis Obispo planning area.

It should be noted that considerable confusion exists as to the application of the term seiche. The definition in Glossary of Geology (1972) limits a true seismic seiche to standing waves set up by the passage of seismic waves from an earthquake. Traveling waves set-up by landsliding into or within a lake or reservoir, or those induced by the tilting of the water body, are not true seismic seiches. Dramatic examples of damage attributed at least in part to seiching at Hebgen Lake in Montana in 1959 (U.S. Geological Survey, et al., 1964) or at Kenai Lake in Alaska in 1964 (McCulloch, 1966) are more likely the results of traveling waves (or reflected traveling waves) set-up by landsliding or the tilting of the reservoir bottom. Significant tilting of major reservoirs or lakes is not expected in the study area, and the potential hazard from landslide-induced waves has been discussed previously under Landslides.

# APPENDICES

# APPENDIX A

# GLOSSARY OF TERMS

Active Fault - One that has moved in recent geologic time and which is likely to move again in the relatively near future. Definitions for planning purposes extend on the order of 10,000 years or more back and 100 years or more forward.

Alluvial - Pertaining to or composed of alluvium, or deposited by a stream or running water. (AGI, 1972)

Alluvium - A general term for clay, silt, sand, gravel, or similar unconsolidated detrital material deposited during comparatively recent geologic time by a stream or other body of running water as a sorted or semisorted sediment in the bed of the stream or on its flood plain or delta, or as a cone or fan at the base of a mountain slope. (AGI, 1972)

Amplification - Elaboration; augmentation; addition (Webster). As used herein, near-surface amplification is the augmentation of wave amplitude resulting from the change in physical properties in near-surface layers (see Introduction).

Amplitude - The extent of the swing of a vibrating body on each side of the mean position. (Webster)

Block Glide - A translational landslide in which the slide mass remains essentially intact, moving outward and downward as a unit, most often along a pre-existing plane of weakness such as bedding, foliation, joints, faults, etc. (AGI, 1972)

Cohesion - Shear strength in a sediment not related to interparticle friction. (AGI, 1972)

Colluvium - (a) A general term applied to any loose, heterogenous, and incoherent mass of soil, material or rock fragments deposited chiefly by mass-wasting, usually at the base of a steep slope or cliff. (b) Alluvium deposited by unconcentrated surface runoff or sheet erosion, usually at the base of a slope. (AGI, 1972)

Compaction - Reduction in bulk volume or thickness of, or the pore space within, a body of fine-grained sediments in response to the increasing weight of overlying material that is continually being deposited, or to the pressure resulting from earth movements within the crust. It is expressed as a decrease in porosity brought about by a tighter packing of the sediment particles. (AGI, 1972)

Consolidated Material - Soil or rocks that have become firm as a result of compaction.

Critical Damping - Damping to the point at which the displaced mass just returns to its original position without oscillation (AGI, 1972).

Damping - The resistance to vibration that causes a decay of motion with time or distance, e.g. the diminishing amplitude of an oscillation. (AGI, 1972)

Displacement (Geological) - The relative movement of the two sides of a fault, measured in any chosen direction; also, the specific amount of such movement. Displacement in an apparently lateral direction includes strike-slip and strike separation; displacement in an apparently vertical direction includes dip-slip and dip separation. (AGI, 1972)

Epicenter - That point on the Earth's surface which is directly above the focus of an earthquake (AGI, 1972)

Fault - A surface or zone of rock fracture along which there has been displacement, from a few centimeters to a few kilometers in scale. (AGI, 1972)

Fault Surface - In a fault, the surface along which displacement has occurred. (AGI, 1972)

Fault System - Two or more interconnecting fault sets. (AGI, 1972)

Fault Zone - A fault zone is expressed as a zone of numerous small fractures or by breccia or fault gouge. A fault zone may be as wide as hundreds of meters. (AGI, 1972)

Focus (Seism) - That point within the Earth which is the center of an earthquake and the origin of its elastic waves. Syn: hypocenter; seismic focus; centrum (see Introduction). (AGI, 1972)

Ground Response - A general term referring to the response of earth materials to the passage of earthquake vibration. It may be expressed in general terms (maximum acceleration, dominant period, etc.), or as a ground-motion spectrum.

Hypocenter - See focus.

Intensity (earthquake) - A measure of the effects of an earthquake at a particular place on human and/or structures. The intensity at a point depends not only upon the strength of the earthquake, or the earthquake magnitude, but also upon the distance from the point to the epicenter and the local geology at the point. (AGI, 1972)

Isoseismal line - A line connecting points on the Earth's surface at which earthquake intensity is the same. It is usually a closed curve around the epicenter. Syn: isoseism; isoseismic line; isoseismal. (AGI, 1972)

Liquefaction - A sudden large decrease in the shearing resistance of a cohesionless soil, caused by a collapse of the structure by shock or strain, and associated with a sudden but temporary increase of the pore fluid pressure. (AGI, 1972)

Macroseismic data - Used herein to describe instrumentally recorded earthquakes generally in the range of Richter magnitude 3.0 or more. (This use differs from the AGI definition of "macroseismic observations").

Magnitude (earthquake) - A measure of the strength of an earthquake or the strain energy released by it, as determined by seismographic observations. As defined by Richter, it is the logarithm, to the base 10, of the amplitude in microns of the largest trade deflection that would be observed on a standard torsion seismograph (static magnification - 2800; period = 0.8 sec; damping constant - 0.8) at a distance of 100 kilometers from the epicenter. (AGI, 1972)

Microseismic data - Used herein to describe instrumentally recorded earthquakes generally in the range of Richter magnitude 3.0 or less. (This use is consistent with the AGI definition of microseism and microseismometer, but is more restricted than their definition of microseismic data).

Natural period - The period at which maximum response of a system occurs. The inverse of resonant frequency.

Normal fault - A fault in which the hanging wall appears to have moved downward relative to the footwall. The angle of the fault is usually 45-90 degrees. This is dip-separation, but there may or may not be dip-slip. (AGI, 1972)

Predominant period - The period of the acceleration, velocity or displacement which predominates in a complex vibratory motion. In the analysis of earthquake vibrations, predominant period is normally the period of the maximum amplitude of the acceleration spectrum.

Response Spectra - An array of the response characteristics of a structure or structures ordered according to period or frequency. The structures are normally single-degree-of-freedom oscillators, and the characteristics may be displacement, velocity or acceleration

Seiche - All standing waves on any body of water whose period is determined by resonant characteristics of the containing basin as controlled by its physical dimensions. (U.S. Geol. Survey Prof. Paper 544-E)

Seismic seiche - Stnading waves set up on rivers, reservoirs, ponds and lakes at the time of passage of seismic waves from an earthquake (U.S. Geol. Survey Prof. Paper 544-E)

Shear - A strain resulting from stresses that cause or tend to cause contiguous parts of a body to slide relatively to each other in a direction parallel to their plane of contact; specifically, the ratio of the relative displacement of these parts to the distance between them. (AGI, 1972)

Shear wave or S-wave - That type of seismic body wave which is propagated by a shearing motion of material so that there is oscillation perpendicular to that direction of propagation. It does not travel through liquids. (AGI, 1972)

Slip - On a fault, the actual relative displacement along the fault plane of two formerly adjacent points on either side of the fault. Slip is three dimensional, whereas separation is two dimensional. (AGI, 1972)

Strike-slip fault - A fault, the actual movement of which is parallel to the strike (trend) of the fault. (AGI, 1972)

Subsidence - A local mass movement that involves principally the gradual downward settling or sinking of the solid Earth's surface with little or no horizontal motion and that does not occur along a free surface (not the result of a landslide or failure of a slope.) (AGI, 1972)

Tectonic - Of or pertaining to the forces involved in, or the resulting structures or features of the upper part of the Earth's crust. (Mod. from AGI, 1972)

Tsunami - A gravitational sea wave produced by any large-scale, short-duration disturbance of the ocean floor, principally by a shallow submarine earthquake, but also by submarine earth movement, subsidence, or volcanic eruption, characterized by great speed of propagation (up to 950 km/hr.), long wavelength (up to 200 dm.), long period (5 min. to a few hours, generally 10 - 60 min.), and low observable amplitude on the open sea, although it may pile up to great heights (30 m. or more) and cause considerable damge on entering shallow water along an exposed coast, often thousands of kilometers from the source. (AGI, 1972)

Unconsolidated material - A sediment that is loosely arranged or unstratified or whose particles are not cemented together, occurring either at the surface or at depth. (AGI, 1972)

Water table - The surface between the zone of saturation and the zone of aeration; that surface of a body unconfined ground water at which the pressure is equal to that of the atmosphere. (AGI, 1972)

# APPENDIX B

## SUMMARY OF SIGNIFICANT COURT DECISIONS AND LEGISLATION

(Source: Urban Geology Master Plan for California, 1973)

In recent years there have been many attempts by government to reduce losses from geologic hazards. The following summaries are some of the more important ones.

## COURT DECISIONS

1. Sheffet decision (Los Angeles Superior Court Case No. 32487): Declared that a public entity is liable for damages to adjacent property resulting from improvements planned, specified or authorized by the public entity in the exercise of its governmental power. (The State Supreme Court refused to rehear this decision, which establishes a judicial precedent.)
2. L.A. County Superior Court (Case No. 684595 and consolidated cases): This decision found the County liable for damages which may have resulted from roadwork and the placement of fill by the County. This case was in regard to the Portuguese Bend landslide, Palos Verdes Hills, Los Angeles County, California.
3. City of Bakersfield vs Miller (48 Cal. Rptr. 889), heard in the State Supreme Court 1966: This decision affirms that the city may declare an older structure not in compliance with the newly adopted Uniform Building Code to be a public nuisance. Further, the city may enforce abatement of the non-conforming condition even though to do so may require the building to be demolished.
4. Burgess vs Conejo Valley Development Co. (Connor vs. Great Western Savings and Loan Association) (73 Cal. Rptr. 369) heard in the State Supreme Court in 1968, concerning damage to tract homes from expansive soil in Thousand Oaks, Ventura County: This decision affirmed that the home buyer, both first buyer and all subsequent ones, has the right to protection from negligent construction practice leading to damage. In this case, neither contractor, county inspectors, nor representatives of the major lending institution acted to ascertain expansive soil conditions, or to prevent damage from them.
5. Oakes vs. The McCarthy Co. (California Appellate Reports, 2nd Series, 267, 1968) the court held that in the Palos Verdes area, Los Angeles County, a developer and soils engineering company could be liable in negligence for damages to a home resulting from using improper (clay) fill material and improperly compacting that fill so that earth movement resulted. Also, the court awared punitive damages against the developer for fraudulent concealment of material facts concerning the property, i.e., failure to volunteer to the prospective buyer that the house was built upon fill.

## LEGISLATION

### PUBLIC RESOURCES CODE

Section 660-662 and 2621-2625: These sections require the State Geologist to delienate special studies zones encompassing potentially and recently active fault traces. It requires cities and counties to exercise specified approval authority with respect to real estate developments or structures for human occupancy within such delineated zones.

Section 2700-2708: These sections require the Division of Mines and Geology to purchase and install strong-motion instruments (to measure the effects of future earthquakes) in representative structure and geologic environments throughout the state.

Section 2750: Establishes a state mining and minerals policy which, among other things, encourages wise use of mineral resources.

### EDUCATION CODE

Section 15002.1: This section requires that geological and soils engineering studies be conducted on all new school sites and on existing sites where deemed necessary by the Department of General Services.

Section 15451-15466: These sections constitute the Field Act and require that public schools be designed for the protection of life and property. These sections, enacted in 1933 after the Long Beach earthquake, are enforced by the State Office of Architecture and Construction in accordance with regulations contained in Title 21 of the California Administrative Code.

HEALTH AND SAFETY CODE

Sections 15000 et seq.: These sections require that geological and engineering studies be conducted on each new hospital or additions affecting the structure on an existing hospital, excepting therefrom one story Type V buildings 4000 sq. ft. or less in area.

Sections 19100-19150: These sections constitute the Riley Act and require certain buildings to be constructed to resist lateral forces, specified in Title 24 California Administrative Code.

Section 17922, 17951-17958.7: These sections require cities and counties to adopt and enforce the Uniform Building Code, including a grading section (chap. 70), a minimum protection against some geologic hazards.

BUSINESS AND PROFESSIONAL CODE

Section 7800-7887: These sections provide for registration of geologists and geophysicists, and the certification of certain geologists in the specialty of engineering geology.

Section 11010: This section requires that a statement of the soil conditions be prepared and needed modifications be carried out in accordance with the recommendations of a registered civil engineer.

Section 11100-11629: These sections require studies in subdivisions to evaluate the possibilities of flooding and unfavorable soils.

GOVERNMENT CODE

Section 8589.5: This section requires that inundation maps and emergency evacuation plans be completed for areas subject to inundation by dam failure.

Section 65300-65302.1: These sections require that each city and county shall adopt the following elements:

Seismic Safety Element consisting of the identification and appraisal of seismic hazards including an appraisal of landsliding due to seismic events.

Conservation element including the conservation, development and utilization of minerals.

Safety element including protection of the community from geologic hazards including mapping of known geologic hazards.

# APPENDIX C

# EARTHQUAKE SAFETY PROCEDURES

Before an Earthquake

1. Potential earthquake hazards in the home should be removed or corrected. Top-heavy objects and furniture, such as bookcases and storage cabinets, should be fastened to the wall and the largest and heaviest objects placed on lower shelves. Water heaters and other appliances should be firmly bolted down, and flexible connections should be used whenever possible.

2. Supplies of food and water, flashlight, a first-aid kit, and a battery-powered radio should be set aside for use in emergencies. Of course, this is advisable for other types of emergencies, as well as for earthquakes.

3. One or more members of the family should have a knowledge of first aid procedures because medical facilities nearly always are overloaded during an emergency or disaster, or may themselves be damaged beyond use.

4. All responsible family members should know what to do to avoid injury and panic. They should know how to turn off the electricity, water, and gas; they should know the locations of the main switch and valves. This is particularly important for teenagers who are likely to be alone with smaller children.

5. It is most important for a resident of California to be aware that this is "earthquake country" and that earthquakes are most likely to occur again where they have occurred before. Building codes that require earthquake-resistant construction should be rigorously enforced. If effective building codes and grading ordinances do not exist in your community, support their enactment.

During An Earthquake

1. The most important thing to do during an earthquake is to remain calm. If you can do so, you are less likely to be injured. If you are calm, those around you will have a greater tendency to stay calm, too. Make no moves or take no action without thinking about the possible consequences. Motion during an earthquake is not constant; commonly, there are a few seconds between tremors.

2. If you are inside a building, stand in a strong doorway or get under a desk, table, or bed. Watch for falling plaster, bricks, light fixtures, and other objects. Stay away from tall furniture, such as china cabinets, bookcases, and shelves. Stay away from windows, mirrors, and chimneys. In tall buildings, it is best to get under a desk if it is securely fastened to the floor, and to stay away from windows or glass partitions.

3. Do not rush outside. Stairways and exits may be broken or may become jammed with people. Power for elevators and escalators may have failed. Many of the 115 persons who perished in Long Beach and Compton in 1933 ran outside only to be killed by falling debris and collapsing chimneys. If you are in a crowded place such as a theater, athletic stadium, or store, do not rush for an exist because many others will do the same thing. If you must leave a building, choose your exit with care and, when going out, take care to avoid falling debris and collapsing walls or chimneys.

4. If you are outside when an earthquake strikes, try to stay away from high buildings, walls, power poles, lamp posts, or other structures that may fall. Falling or fallen electrical power lines must be avoided. If possible, go to an open area away from all hazards but do not run through the streets. If you are in an automobile, stop in the safest possible place, which, of course, would be an open area, and remain in the car.

After An Earthquake

1. After an earthquake, the most important thing to do is to check for injuries in your family and in the neighborhood. Seriously injured persons should not be moved unless they are in immediate danger of further injury. First aid should be administered, but only by someone who is qualified.

2. Check for fires and fire hazards. If damage has been severe, water lines to hydrants, telephone lines, and fire alarm systems may have been broken; contacting the fire department may be difficult. Some cities, such as San Francisco,

have auxiliary water systems and large cisterns in addition to the regular system that supplies water to fire hydrants. Swimming pools, creeks, lakes, and fish ponds are possible emergency sources of water for fire fighting.

3. Utility lines to your house - gas, water, and electricity - and appliances should be checked for damage. If there are gas leaks, shut off the main valve which is usually at the gas meter. Do not use matches, lighters, or open-flame appliances until you are sure there are no gas leaks. Do not use electrical switches or appliances if there are gas leaks, because they give off sparks which could ignite the gas. Shut off the elctrical power if there is damage to the wiring; the main switch usually is in or next to the main fuse or circuit breaker box. Spilled flammable fluids, medicines, drugs, and other harmful substances should be cleaned up as soon as possible.

4. Water lines may be damaged to such an extent that the water may be off. Emergency drinking water can be obtained from water heaters, toilet tanks, canned fruits and vegetables, and melted ice cubes. Toilets should not be flushed until both the incoming water lines and outgoing sewerlines have been checked to see if they are open. If electrical power is off for any length of time, plan to use the foods in your refrigerator and freezer first before they are spoiled. Canned and dried foods should be saved until last.

5. There may be much shattered glass and other debris in the area, so it is advisable to wear shoes or boots and a hard hat if you own one. Broken glass may get into foods and drinks. Liquids can be either strained through a clean cloth such as a handkerchief or decanter. Fireplaces, portable stoves, or barbecues can be used for emergency cooking but the fireplace chimney should be carefully checked for cracks and other damages before being used. In checking the chimney for damage, it should be approached cautiously, because weakened chimneys may collapse with the slightest of aftershocks. Particular checks should be made of the roof line and in the attic because unnoticed damage can lead to a fire. Closets and other storage areas should be checked for objects that have been dislodged or have fallen, but the doors should be opened carefully because of objects that may have fallen against them.

6. Do not use the telephone unless there is a genuine emergency. Emergencies, and damage reports, alerts, and other information can be obtained by turning on your radio. Do not go sightseeing; keep the streets open for the passage of emergency vehicles and equipment. Do not speculate or repeat the speculations of other - this is how rumors start.

7. Stay away from beaches and other waterfront areas where seismic sea waves (tsunamis), sometimes called "tidal waves", could strike. Again, your radio is the best source of information concerning the likelihood that a seismic sea wave will occur. Also stay away from steep landslide-prone areas if possible, because aftershocks may trigger a landslide or avalanche, especially if there has been a lot of rain and the ground is nearly saturated. Also stay away from earthquake-damaged structures. Additional earthquake shocks known as "aftershocks" normally occur after the main shock, sometimes over a period of several months. These are usually smaller than the main shock but they can cause damage, too, particularly to damaged and already weakened structures.

8. Parents should stay with young children who may suffer psychological trauma if parents are absent during the occurences of aftershocks.

9. Cooperate with all public safety and relief organizations. Do not go into damaged areas unless authorized; you are subject to arrest if you get in the way of, or otherwise hinder, rescue operations. Martial law has been declared in a number of earthquake disasters. In the 1906 disaster in San Francisco, several looters were shot.

10. Send information about the earthquake to the Seismological Field Survey to help earth scientists understand earthquakes better.

# APPENDIX D

# GENERAL CHARACTERISTICS OF EARTHQUAKES

## A. GENERAL CHARACTERISTICS OF EARTHQUAKES

### 1. The Source of Earthquakes

Earth scientists are generally agreed that earthquakes originate as the result of an abrupt break or movement of the rock in the relatively brittle crust of the earth. The earthquake is the effect of the shock waves generated by the break, much the same as sound waves (a noise) are generated by breaking a brittle stick. If the area of the break is small and limited to the deeper part of the crust, the resulting earthquake will be small. However, if the break is large and extends to the surface, then the break can result in a major earthquake.

These breaks in the earth's crust are called faults. In California, faults are extremely common, and vary from the small breaks of an inch or less that can be seen in almost any road-cut, to the larger faults such as the San Andreas on which movement over many millions of years has amounted to hundreds of miles. In addition to the size of faults, their "age" is also important. Many large faults have not moved for millions of years; they are considered "dead" or "inactive." They were probably the source of great earthquakes millions of years ago but are not considered dangerous today.

Since faults vary as to the likelihood of their being the source of an earthquake, considerable effort has, and is continuing to be expended by geologists and seismologists to determine and delineate the faults likely to generate significant earthquakes. These faults are classified generally as follows:

(1) An historically active fault is one which is known to have slipped during historical time, or one which is associated with an alignment of earthquake epicenters. In California this "historical time" span is limited to approximately 150 years.

(2) An active fault is one that has moved in the recent geologic past, and that can be expected to move again in the foreseeable future. The "recent geologic past" is generally interpreted to include recent geologic time; a period of approximately 10,000 years. However, a precise definition of "active fault," such as is needed where the term is included in legal documents, is still a matter of considerable debate.

(3) A potentially active fault is one that lacks the criteria to be classified as active, but which must be considered suspect because of offset of Quaternary sediments (up to approximately 2 million years old) or the presence of scattered earthquake epicenters. This classification, may be applied as much due to lack of definitive data as to the presence of data that definitely precludes recent movement.

### 2. Describing an Earthquake

Several terms are used to describe the location, "size," and effects of an earthquake. A clear understanding of the meaning of these terms and their limitations is essential to an understanding of the results of the investigation.

The location of an earthquake is generally given as the epicenter of the earthquake. This is a point on the earth's surface vertically above the hypocenter or focus of the quake. The latter is the point from which the shock waves first emanate. However,

as discussed above, earthquakes originate from faults. These are surfaces not points, so the hypocenter is only one point on the surface (or volume) that is the source of the earthquake.

Magnitude describes the size of the earthquake itself. Technically, it is defined as the logarithm of the maximum amplitude recorded on a standard seismograph at 100 kilometers (62 miles) from the epicenter. The most important part of this definition is that it is a logarithmic scale and an increase of one in magnitude (e.g., magnitude 5.0 to 6.0) represents an increase of 10 in the amplitude of the recorded wave. It should also be noted that the magnitude of an earthquake is determined at a considerable distance from the epicenter of the earthquake, and that it is based on ground displacement rather than ground acceleration.

Intensity describes the degree of shaking in terms of the damage at a particular location. The scale used today is the Modified Mercalli Scale, and is composed of 12 categories (I to XII) of damage as described in Table 1. The Roman numerals are used to emphasize that the units in the scale are descrete categories rather than a continuous numerical sequence as is the magnitude scale. It is important to remember that intensity is a very general description of the effects of an earthquake, and depends not only on the size of the quake and the distance to its center, but also on the quality of the construction that has been damaged and the nature of local ground conditions.

TABLE 1. MODIFIED MERCALLI INTENSITY SCALE OF 1931
(from United States Earthquakes)

| Intensity | Description of Damage |
|---|---|
| I | Not felt except by a very few under specially favorable circumstances. (I Rossi-Forel Scale) |
| II | Felt only by a few persons at rest, especially on upper floors of buildings. Delicately suspended objects may swing. (I to II Rossi-Forel Scale) |
| III | Felt quite noticeably indoors, especially on upper floors of buildings, but many people do not recognize it as an earthquake. Standing motorcars may rock slightly. Vibration like passing of truck. Duration estimated. (III Rossi-Forel Scale) |
| IV | During the day, felt indoors by many, outdoors by few. At night, some awakened. Dishes, windows, doors disturbed; walls make creaking sound. Sensation like heavy truck striking building. Standing motorcars rocked noticeably. (IV to V Rossi-Forel Scale) |
| V | Felt by nearly everyone, many awakened. Some dishes, windows, etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of trees, poles, and other tall objects sometimes noticed. Pendulum clocks may stop. (V to VI Rossi-Forel Scale) |
| VI | Felt by all, many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight. (VI to VII Rossi-Forel Scale) |
| VII | Everybody runs outdoors. Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerably in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motorcars. (VIII Rossi-Forel Scale) |
| VIII | Damage slight in specially designed structures; considerable in ordinary, substantial buildings, with partial collapse; great in poorly built structures. Panel walls thrown out of frame structures. Fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well water. Persons driving motorcars disturbed. (VIII to IX Rossi-Forel Scale) |
| IX | Damage considerable in specially designed structures; well-designed, frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken. (IX Rossi-Forel Scale) |
| X | Some well-built wooden structures destroyed; most masonry and frame structures destroyed with their foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and steep slopes. Shifted sand and mud. Water splashed (slopped) over banks. (X Rossi-Forel Scale) |
| XI | Few, if any, (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipelines completely out of service. Earth slumps and land slips in soft ground. Rails bent greatly. |
| XII | Damage total. Waves seen on ground surfaces. Lines of sight and level distorted. Objects thrown upward into air. |

### 3. Occurrence and Recurrence of Earthquakes

Earthquakes have had in the past a certain occurrence in space and time. These occurrences may or may not set certain patterns that can form the basis for predicting their occurrence in the future. When such occurrences are analyzed in time, certain characteristics may statistically recur at definite intervals. If it can be shown that a particular magnitude earthquake recurs on a fault on the average of a certain number of years, this number can be said to be the recurrence interval for the magnitude. If the interval of time is set (e.g., a 100-year period), then earthquakes of a particular magnitude will recur a certain number of times in the specified period.

In California, as in most large areas, small earthquakes occur much more often than large earthquakes. Also, there is a fairly definite pattern in that the logarithm of the number of events of a particular magnitude that have occurred in the past is approximately proportional to the magnitude of those events. This relationship appears to apply to larger areas such as California and western Nevada, some smaller areas such as the Los Angeles Basin, and to some faults such as the Newport-Inglewood. However, this relationship does not apply to all faults, and it should be applied to small areas, such as cities or individual sites, with great care.

## B. ENGINEERING CHARACTERISTICS OF EARTHQUAKES

The data of seismologists and geologists are, in general, not applicable to the engineering design of earthquake-resistant structures. The seismograph, for example, is a very sensitive instrument designed only to record earthquakes at great distances. A level of shaking that would be meaningful to an engineer in designing a building would put most seismographs completely off-scale.

As a result, it has been necessary to design and install special instruments to record the strong motions of earthquakes that are of interest to the engineer in the design of earthquake-resistant structures. The first such instruments, principally accelerographs and seismoscopes, were installed by the U.S. Coast and Geodetic Survey in the late 1920's and the 1933 Long Beach earthquake was the first real test of the system. The motions were apparently stronger than expected, and the accelerograph record from Long Beach itself has never been adequately deciphered. Since that time, the instrumentation and analytical techniques have been continuously improved, and many excellent records have been obtained of the more recent strong earthquakes.

The following sections are a brief introduction to the concepts, data, and application of strong-motion records. The science is relatively young, and tends to grow in bursts following the recording of a damaging earthquake.

## 1. Acceleration, Velocity, and Displacement

The accelerograph is a short-period instrument (in contrast to the seismograph), and measures the acceleration of the ground or the structure on which it is mounted. Figure 1 shows the ground acceleration recorded just a few hundred feet from the fault during the 1966 Parkfield earthquake. The velocity and displacement curves have been derived from it by integration. It is a particularly good example of the relationships of these three parameters of motion because of the relatively "clean", single-displacement pulse that corresponds to two velocity peaks and four acceleration peaks. Figure 2 shows the more typically complex record of the San Fernando earthquake as recorded at Pacoima Dam. Neither of the two, however, are typical records in terms of accelerations recorded. The Pacoima record shows the largest acceleration recorded to date (1.25g), and the Parkfield record (0.5g) was the largest before the San Fernando earthquake.

It should also be noted that accelerographs normally record three components; two in the horizontal plane at right angles to each other, and one vertical. Only one component is shown in each of the two examples.

Maximum acceleration is one of the basic parameters describing ground shaking, and has been the one most often requested by agencies such as FHA in determining the earthquake hazard to residential structures. It is particularly important for "low-rise" construction (up to 3 to 5 stories) and other structures having natural periods

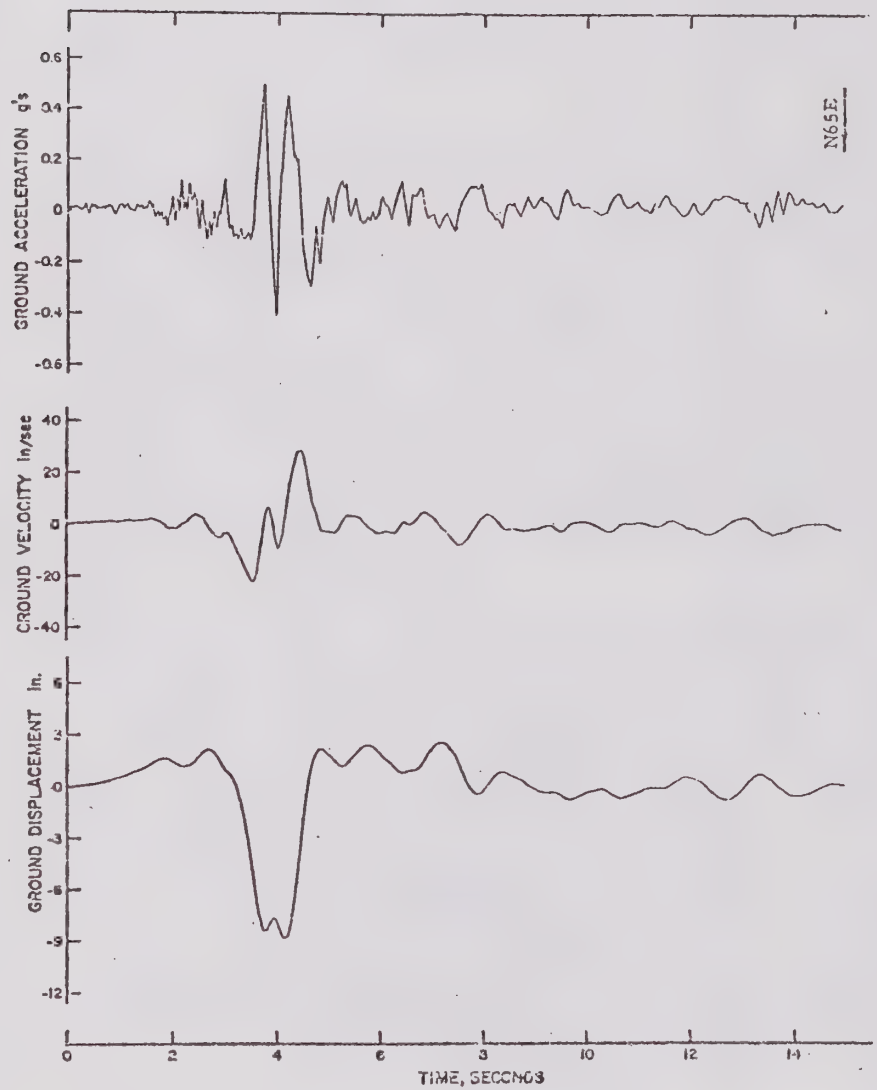


Figure 1. Acceleration, velocity, and displacement for Parkfield earthquake of June, 1966 at Station 2, N65E. From Housner and Trifunac, 1967.

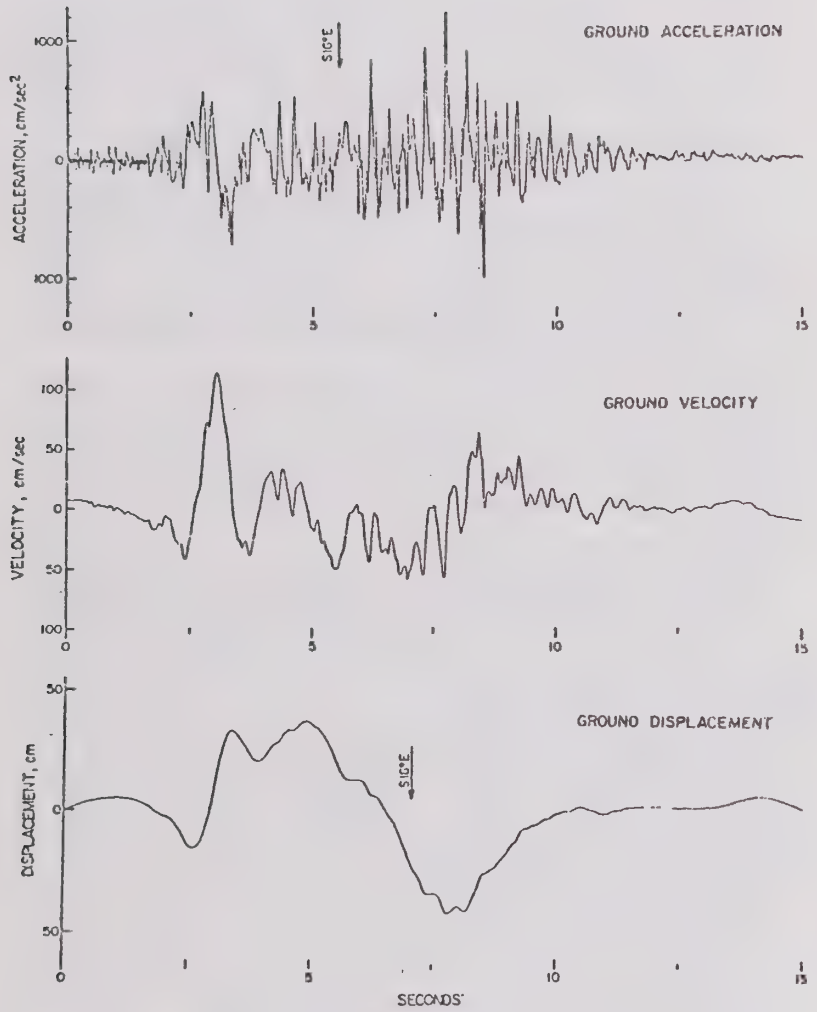


Figure 2. Acceleration, velocity and displacement in the S16°E component of Pacoima Dam record, San Fernando earthquake of February 9, 1971, 0:600 (PST). From Trifunac and Hudson, 1971.

in the range of 0.3 - 0.5 seconds or less.

2. <u>Frequency Content - Fourier and Response Spectra</u>

The frequency content of the ground motion is particularly important for the intermediate and higher structures. The problem can be compared to pushing a child in a swing. If the pushes are timed to coincide with the natural period of the swing, then each push makes the swing go higher. The situation is similar during earthquakes. Structures have certain periods of vibration. If the pulses of the earthquake match the natural period of the structure, even a moderate earthquake can cause damaging movement. However, if the match is poor, the movement and resulting damage will be much less.

Two methods are commonly used to analyze and display the frequency content of an earthquake. A <u>Fourier analysis</u> is a common mathematical method of deriving the significant frequency characteristics of a time-signal such as the record of an earthquake. The results of the analysis are an amplitude term and a phase term. The amplitude is normally plotted against the period for that amplitude to give a Fourier amplitude spectrum for the range of frequencies that are of interest. Since the mathematical procedure is basically an integration of acceleration with time, the Fourier amplitude has the units of velocity.

A response spectrum is derived by a similar mathematical process, but is slightly different in concept. It represents the maximum response of a series of oscillators,

having particular periods and damping, when subjected to the shaking of the earthquake. The result is also expressed in terms of velocity with the particular nomenclature depending on the precise method used to derive the spectrum.

The Fourier spectrum can be generally described as the energy available to shake structures having various natural frequencies. The response spectrum gives the effect, in maximum velocity, of this available energy on simple structures having various frequencies and damping. At zero damping the two are very similar. Figure 3 shows a plot of both the Fourier spectrum and the response spectrum with zero damping for the Taft earthquake of 1952. Figure 4 shows the response spectrum for the Parkfield record (Figure 1) for several levels of damping.

3. <u>Near Surface Amplification</u>

The shock waves of an earthquake radiate outward from the source (i.e., the slipped fault) through the deeper and relatively more dense parts of the earth's crust. In this medium, the waves travel at high velocity and with relatively low amplitude. However, as they approach the surface, the velocity of the medium decreases and may become quite variable if layers of different rock types are present. The overall effect is generally an amplification of the wave or of certain frequencies within the spectrum of the wave.

The most consistently applicable effect is the increase in wave amplitude that accompanies the decrease in velocity. This relationship can be compared to laws

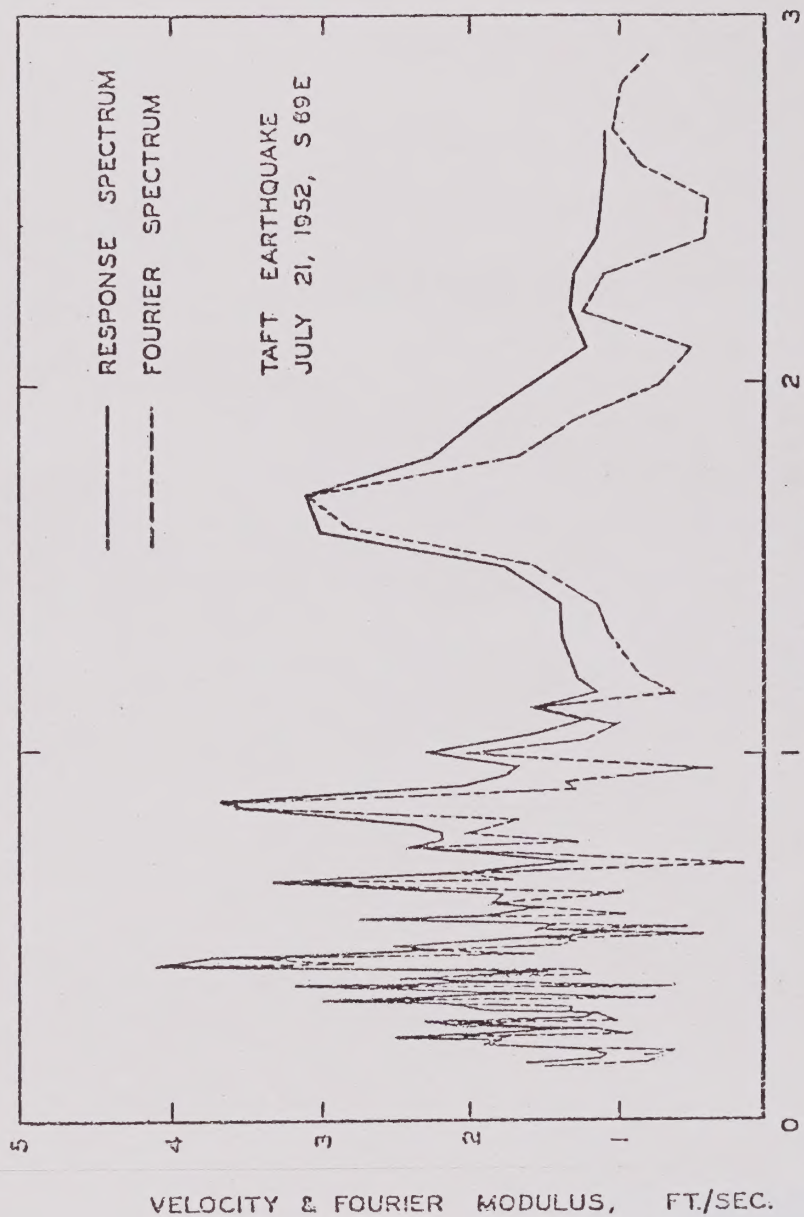


Figure 3. Fourier and response spectra, Taft record, 1957 Kern County earthquake. From Alford et al, 1964.

of mechanics that require the conservation of energy and momentum. In the case of earthquake waves, the energy of velocity is transferred to energy of wave amplitude when the velocity decreases.

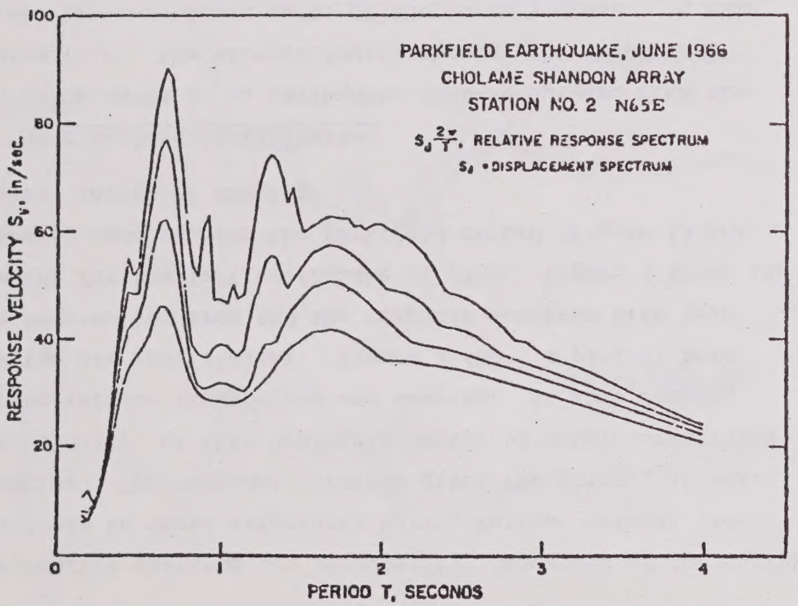


Figure 4. Response spectra for Parkfield earthquake of June, 1966 at Station 2, N65E. Curves are for 0, 2, 5 and 10% damping. From Housner and Trifunac, 1967.